An examination of changes in rainfall, streamflow and landcover: a case study of the Kandelaars catchment, Oudtshoorn, South Africa 1926 to 2008

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Plagiarism Declaration

I, Takunda Mambo, do hereby declare that the work contained within this thesis is my own.

I understand that plagiarism is wrong; and, thus all sources of materials used for the research have been acknowledged accordingly.

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Dedication

I dedicate this thesis to my uncle Humphrey who passed away in a tragic car accident in Zimbabwe, in April 2011.

Abstract

This study seeks to understand changes in rainfall and land-cover in the Kandelaars catchment, which are documented drivers that influence the magnitude, seasonality, and trends in flash-flood occurrence.

The study site is situated South-West of the town of Oudtshoorn, which is part of a semi-arid basin, found between the Swartberg, Rooiberg, Outeniqua and Kammanassie mountains. This area is documented for its extensive agricultural activity in the form of ostrich farming, which has been practised there for over a century. In addition, the area is also exposed to seasonally extreme meteorological conditions, most notably in the form of cut-off lows, which have been projected to intensify with the changing climate.

Despite the rich culture of ostrich farming, which has played a pivotal role in the development of the town, the intensity and consistency of the practice has come to be an environmental burden to the land, which is also exposed to intense rainfall. These have resulted in the reporting of major economic losses in the recent past, due to floods. This was the case on 29 June 2011, when three zones around the municipality were subjected to flooding, which resulted in losses amounting to R120 million. In this instance, part of the Kandelaars catchment, located in zone three, was subjected to almost R40 million in flood-related losses.

Owing to the locality of the Kandelaars catchment, and its documented practice of ostrich farming, the study sought to investigate changes in rainfall and vegetation cover, which are documented drivers that influence the magnitude, seasonality, and trends in flash-flood occurrence. The study revealed that rainfall has a very strong relationship with river discharge levels. Rainfall records revealed a shift in seasonality to later in the year, and an increase in the frequency and intensity of events in recent

years. Similarly, this trend was observed in the results of the river-flow records. The study also indicated that there has been a significant amount of agricultural expansion, particularly in the upper catchment and along the riparian zones. Ostrich farming has led to extensive vegetation removal, in many instances leaving surfaces bare, with rocks and stones exposed. This was largely the case where birds were restricted to confined spaces. In addition, other forms of livestock rearing, specifically sheep and cattle, have also led to land-cover alteration and vegetation removal.

Abbreviations

APFM	Associated Programme on Flood Management
AMS	Annual Maximum Series
CRED	Centre for Research on the Epidemiology of Disasters
DiMP	Disaster Mitigation for Sustainable Livelihoods Programme
DWA	Department of Water Affairs
DRDLR	Department of Rural Development and Land Reform
EDA	Exploratory Data Analysis
ENPAT	Environmental Potential Atlas
ERDAS	Earth Resources Data Analysis System
GIS	Geographic Information Systems
GCM	General Circulation Models
Landsat TM	Landsat Thematic Mapper
Landsat ETM+	Landsat Enhanced Thematic Mapper Plus
ND	No Date
NGI	National Geo-spatial Information
PDS	Partial Duration Series
PoT	Point of Threshold
SAOBC	South African Ostrich Business Chamber
SANRAL	South African National Road Agency Limited
SAWS	South African Weather Services
SCS	United States Soil Conservation Service
SPOT	Système Pour l'Observation de la Terre
UN	United Nations

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Chapter One: Introduction

1.1 Introduction

Recent global hazard assessments have identified floods as being the most damaging natural hazards (UN-Water, 2005; Munich re, 2007; Gupa-Sapir *et al.*, 2011). This has been attributed to their frequency, evidenced by over 3,500 documented flood disasters since 1990 (Smith & Petley, 2009; Wisner *et al.*, 2012), in conjunction with increasing exposure of assets, as documented annually by the Centre for Research on the Epidemiology of Disasters (CRED) database.

Subsequently, these hydrological disasters affect an average of 190 million people per annum (UN-Water, 2005; Gupa-Sapir *et al.*, 2011).

Similarly, within South Africa, flooding constitutes an important disaster risk, with all provinces documented to have experienced flood events from 1900 to 2010 (WAMTechnology, 2011). However, in South Africa recorded flood losses are unevenly distributed geographically, with the Western Cape reportedly the most flood-prone province, followed by Kwa-Zulu Natal, and then the Eastern Cape (National Disaster Management Centre, 2006).

Detailed ex-post studies of flood disasters, from 2003 to 2008, within the Western Cape Province illustrate the impact of recurrent flooding, with direct economic losses exceeding R2.5 billion (DiMP, 2010). The same recent report noted that the majority of the losses were attributed to severe weather events, specifically cut-off low pressure systems, which affected all districts within the province over the six year study period. In addition, following normalization of the population data and adjustment for household income, consolidated economic losses for 2007 and 2008 were shown to be disproportionately higher for inland municipalities (DiMP, 2010). This was clearly illustrated in the case of Oudtshoorn municipality, which, in 2007, sustained the third-highest municipal losses. These amounted to R96.7 million, and were attributed primarily to agricultural and provincial road impacts (DiMP, 2010).

Within the past year, the Oudtshoorn Local Municipality has sustained further flood related losses. On 29 June 2011, a cut-off low pressure system generated heavy rainfall across the Eden District resulting in damaging floods with estimated losses in the Oudtshoorn Local Municipality exceeding R120 million (Agri Klein Karoo, pers comm., 2012). These flood impacts were reported from farms across the municipality, including those located in the Kandelaars River catchment situated South-West of Oudtshoorn town.

Officials from the Department of Agriculture had identified the Kandelaars River catchment as flood-prone, following damage sustained in 2007 (Department of Agriculture, pers comm, 2009), and suggested this constituted a useful study site for applied flood research.

1.2 Rationale, aim and objectives

1.2.1 Rationale and aim

The increasing occurrence of damaging floods in the Kandelaars Catchment, in Oudtshoorn, may be attributed to different contributing risk factors. These include greater climate variability associated with more intense weather events (Kundewicz; 2004; Midgley *et al.*, 2005; Midgley *et al.*, 2010), or with increasing exposure of assets (UN, 2010). However, a higher frequency of damaging floods may also be due to changing catchment attributes that, by altering surface processes, could harden catchment conditions, and influence riverine discharge (Alexander, 1993; Smith & Petley, 2009). Similarly, changed catchment conditions may also result from diminished vegetation cover that leads to lower infiltration and increased surface run-off associated with higher magnitude floods.

However, it is unclear whether increasing flood occurrence is a consequence of meteorological events or more intense land-use activities within floodplains (Chang *et al*., 2009), or a combination of both. This underlines the value of localised case-studies of rainfall, river flow and land-use change for specific catchments with a recognised flood-risk profile. For instance, recent records on the intensely farmed upper Duiwenshoks catchment indicated increased flood occurrence associated with changing basin characteristics, coupled with increasingly extreme rainfall episodes that resulted in higher magnitude flash flooding (de Waal, 2010).

This study, which focused specifically on the Kandelaars catchment, also sought to investigate changes in land-cover and rainfall that may be associated with higher magnitude floods. Specifically, the study aimed to investigate the rainfall related and land-use risk drivers that contributed to higher magnitude floods within the Kandelaars catchment from 1982 to 2008. In this context, the findings from the study sought to generate insight to strengthen flood risk management in small catchments exposed to recurrent severe weather events.

1.2.2 Study objectives

Specifically, this study was informed by four research objectives. These were to:

1. Investigate rainfall occurrence, in order to identify possible changes in the frequency, magnitude, and seasonality, of extreme rainfalls.
2. Examine river flow, in order to identify possible changes in the frequency and magnitude in extreme river flows.
3. Examine relationships between extreme rainfall occurrence and extreme river flows.
4. Explore changes in agricultural land use that may have influenced overland flow in the catchment.

While a detailed study of 'flood risk' within the Kandelaars would have required research on assets, and exposure, within the floodplain, this exceeded the scope of the study.

1.3 Ethical considerations

For purposes of confidentiality, the informants were identified by their positions and job titles. Sensitive information was neither reported nor displayed in the study without the permission of the relevant parties; and was acknowledged accordingly. Furthermore, copies of the final thesis will be made available to the provincial and municipal disaster-management centres.

1.4 Limitations of the study

Specifically, the rainfall analysis was constrained by the poor and uneven quality of the rainfall data. This was partly attributed to the limited number of rainfall gauges in the catchment, which restricted determination of changing rainfall patterns and distribution, particularly in the upper catchment where more rainfall occurs.

It was also affected by incomplete rainfall records from the Ruitersburg station, located higher up the catchment, where most precipitation takes place. To counter these constraints, the rainfall analysis primarily applied data derived from the Groot Doornriver station for which the record was almost complete.

One limitation in the spatial analysis relates to the lack of sensitivity of the images. For instance, the aerial photographs with poor resolution made specific feature identification particularly challenging. While ArcGIS 9.2 is an appropriate analytical tool for image viewing and the corroboration of different types of data, it is more limited in specific ground feature interpretation. This constraint was partly addressed through a second field visit to the catchment in March 2012.

Lastly, although the agricultural activities in the catchment were assessed during the field visits, the full extent of their contribution to flooding could not be determined. Unfortunately, field observation of actual overland flow was not present. This in part attributed to the semi-arid character of the catchment and infrequent rainfall

1.8 Structure of the thesis

This thesis comprises six chapters. Chapter One introduces the study and provides its background, rationale, aims and objectives and the ethical considerations. Chapter Two reviews the literature that provides the foundation for the study, and the conceptual framework which guides the research process. Chapter Three profiles the geographic and socio-economic characteristics of the research area: The Kandelaars catchment. Chapter Four describes the methods that were used for the study, outlining the data collection tools and consolidation processes. Chapter Five presents the findings and their analysis. Chapter Six concludes the study with a discussion of the findings and presentation of recommendations for future research.

Chapter Two: Literature Review

2.1 Introduction

This chapter introduces relevant literature that guided research on flood occurrence in the Kandelaars catchment. It begins by situating the research within the broader disaster risk domain with a particular focus on flooding as hazard. The chapter continues by describing the major flood types that are associated with adverse impacts. It then outlines natural causes of endangering floods, as well as the respective roles of human settlement, agriculture and climate change as drivers of flood hazards. The chapter continues by providing an overview of frequently used methods for estimating flood magnitude and exposure; and concludes by presenting the conceptual framework, which schematically links the objectives of the study to the methods that will be used in this case study of the Kandelaars catchment.

2.2 Flooding as a disaster risk

2.2.1 Overview

As this study is situated within the disaster risk domain, it gives focus particularly on flood hazards that potentially drive flood risks, which may become realized as measurable flood losses.

In the conceptualisation, the notion of a physical hazard such as a flash flood is defined as "a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage (UNISDR, 2009).

This approach acknowledges that floods are naturally occurring phenomena constituting excessive amounts of water flowing freely within a system, that take place as a result of meteorological or hydrological factors, or both (Hewitt, 1997). In a natural setting, these episodes are important for ecosystem function and maintenance of biodiversity, as they encourage sustenance and regeneration of both flora and fauna (Mitsch *et al.*, 1979; Hughes, 1990; Bayley, 1995). Such regimes have historically enabled the development of human settlements in nutrient rich floodplains. Examples include settlements along the Zambezi, Nile, Indus, Tigris and Yangtze flood plains (Alexander, 1993). However, today flooding is viewed as an important global disaster risk resulting in approximately 62,000 deaths annually, and affecting 190 million people per annum (Gupa-Sapir *et al.*, 2011; Wisner *et al.*, 2012). Therefore, while the study recognises the benefits conferred by naturally occurring floods, it's particular focus is on potentially endangering floods, such as those described below.

2.3 Flooding as a hazard: types of flooding

Depending on the causes and characteristics of such floods, these may be classified in different ways (Hewitt, 1997; Alexander, 2000:15; Kron, 2002; Smith & Petley, 2009:239). For instance, the areal extent covered by floods may vary from small catchments, to areas covering tens of thousands of square kilometres (km^2), as exhibited in the Yangtze River catchment in China (Wang, 2004; Juan *et al.*, 2008). This is due to the diverse forms of floods, and their associated impact (Smith & Petley, 2009). However, a widely used typology is proposed below by the Associated Programme on Flood Management (APFM), a joint initiative of the World Meteorological Organization and the Global Water Partnership. The APFM (2008) proposes four flood categories: riverine, local, coastal, and flash flooding.

2.3.1 Riverine flooding

Riverine flooding is characterized by discharge which overflows onto the river banks, and beyond. It takes place when the runoff generated causes slow and continual rising of the river's surface flow, eventually reaching a point where the volumes flowing downstream subsequently exceed the carrying capacity of the channel (APFM, 2008).

The runoff is generally caused by either intense rainfall over a short duration, or low intensity rainfall over several days (APFM, 2008). In addition, precipitation may combine with melting snow at the end of winter periods - to increase the discharge load, as experienced in the Alps and the Himalayas of Europe and Asia. The receding of the river's level also tends to be prolonged, depending on the topography of the course in the lower catchment. The areas most affected by flooding are located in the low-lying areas of the river's course; and these areas are referred to as the floodplains.

2.3.2 Local flooding

Local flooding encompasses urban, pooling, and pluvial flooding, which occur in built up environments of planned and informal settlements (Benjamin, 2008; DiMP, 2010). This occurs when precipitation fails to penetrate into the ground because of saturation or the impervious nature of the ground cover; and it is mostly associated with urban developments such as roads and pavements. As excess runoff is formed, the urban drainage systems fail to direct the large volumes of water to the river; and the situation is further aggravated by blocked and out-dated drains (Wisner & Pelling, 2008; Falconer *et al.*, 2009; Collier 2009; Falconer, 2010). This causes water to overflow back onto roads and around the built up areas.

Pooling specifically, is a frequently occurring form of flooding in unplanned settlements located in low lying and wetland locations (for example, Sweet Home Farm, Masiphumelele, Kosovo, Thembalethu and Alexandra) (Benjamin, 2008; DiMP, 2010). These areas characteristically have high water tables which rise to generate local flooding without any significant river flow (APFM, 2008; DiMP, 2010).

2.3.3 Coastal flooding

Coastal flooding is the inundation of low lying areas adjacent to the ocean, often causing damage to property and the coastal environment. It occurs when high tides and winds combine during a storm to cause what is termed storm surge (APFM, 2008). These are above average sized waves that are pushed onto low-lying land. The implications of storm surge can be greater in estuarine locations, as the waves thus generated are capable of "impeding the discharge of rivers and drainage systems, leading to local or riverine floods" (APFM, 2008:7). Under these circumstances, the discharge levels remain higher for longer periods.

Tropical cyclones are well known to produce large storm surges that inundate coastal areas on impact. This played a vital role in the overall damage caused by the Mozambique flood in 2000, which affected more than 500,000 people (USAID, 2001). Similarly, the Western Cape belt in South Africa, extending from Camps Bay to Port Elizabeth, is under threat from meteorological events which cause coastal flooding on an annual basis (Alexander, 2000; WAMTechnology, 2011).

2.3.4 Flash flooding

A flash flood constitutes the rapid accumulation of discharge upstream and the transportation of these waters to lower-lying areas of the catchment basin, with classically sharply peaked flood hydrographs (Foody *et al.*, 2004; APFM, 2008). The International Centre for Integrated Mountain Development (ICIMOD) asserts that these are sudden onset floods that are very difficult to predict, and for these reasons they are regarded the as most dangerous of all flood types (ICIMOD, 2010).

The river discharge is increased by vast quantities of precipitation over a period of six hours or less, in the upper catchment area. This is a result of slow moving or multiple thunderstorms (DiMP, 2010).

These floods tend to occur in the small river basins, of mountainous surroundings (Kron, 2008), where the ground cover comprises arid or sparse vegetation cover with low infiltration rates, which promote the formation of rapid surface runoff (Spencer & Stensrud, 1998; Merz & Bloschl, 2009). While the peak discharges are much higher and sharper than other terrestrial floods, the total hydrograph volumes of flash floods are relatively small. Nonetheless, the sharply peaking discharge allows for the water to carry vast amounts of debris, providing a cumulative flow with immense energy to cause serious damage.

2.4 Flood causation: natural factors

This study's focus is on the changing determinants of endangering floods; it emphasises flooding as a hazard. Drawing on Smith and Ward's studies on flood causation (1998), Kundzewicz (2004) and Smith and Petley (2009) underline the importance of primary climatological factors in driving endangering floods, as well as "secondary flood intensifying conditions that are more drainage-basin specific" (Smith & Petley, 2009:239).

Together, these transient and permanent controls (Alexander, 1993:121) influence "the magnitude of the flood, its speed of onset, the velocity, the sediment load of the river and the duration of the event (Smith & Petley, 2009:241). Excessive rainfall is the primary cause of floods. It's contribution, however, may vary from semi-predictable rains covering widespread areas (lasting for periods ranging from days to weeks) (Smith & Petley, 2009) such as the in Yangtze and Ganges deltas which are influenced by the annual monsoon (Mirza *et al.*, 2003; Jiang *et al*, 2005; Zhang *et al.*, 2005), to heavy concentrations of precipitation that affect small basins as may be observed by the floods of 2000 in Prague, Czech Republic (Ulbrich *et al.*, 2003).

Basin characteristics are highly instrumental in changing the implications that rainfall may have on surface runoff, depending on the extent to which these are manipulated. These characteristics comprise all the factors about the catchment where the precipitation is captured. These include the permeability (soil and rock composition, and type of the ground cover), the size, shape, gradient, and, the length and depth of the river channel (Alexander, 1993). Soils and rocks are important as they influence the infiltration rate and the saturation levels. For instance, sandy soils allow water to infiltrate easily into the ground. However, soils of a clay-like or rocky composition tend to inhibit infiltration, thereby enhancing the flow of water overland. Likewise, in relation to rocks, those with fractured formations allow for penetration into the ground up to a certain level. In some cases, large rainfall events are important for ground water recharge (Midgley *et al.*, 2010).

When the infiltration capacity is exceeded, no more water can penetrate the ground and overland flow results. Similarly, the extent and type of ground cover will also influence infiltration. Impermeable surfaces and those with little vegetation encourage surface runoff.

The gradient of the catchment also influences the potential for infiltration to take place, as well as the rate at which surface runoff travels to the river channel. Flatter locations tend to have lower runoff potential for infiltration, whereas mountainous locations have higher potential for runoff, and much faster overland flow. Once this water reaches the river, the deeper the river channel the greater the carrying capacity, whereas small channels easily overflow causing flooding.

2.5 Flood causation: the role of human settlement

The term 'settlement' can be classified both as a form of land use and of land-cover (Meyer & Turner II, 1992). As a land use, this entails a location catering for human habitats, industrial areas of the primary, secondary and tertiary segments of the economic sector, and transportation networks. As a land-cover, it comprises manipulated land surface, which includes buildings and pavements (Meyer & Turner II, 1992), occupying less than 2% of the world's global land-cover surface (Grubler, 1994). Collectively, urban areas are very dynamic as they constitute more than half of the world's global populous in such a small space. By 2025 this figure is expected to rise to approximately 60% (Lambin *et al.*, 2001), and is occurring most rapidly in developing nations. In order to accommodate the growing populations, urbanization has relied on the expansion of transport networks, such as roads, and railway networks, within the respective settlements. These facilitate for greater movement of the growing populations, within the settlements, and movement in and out.

2.5.1 Overview of relationship between human settlements and flood occurrence

Settlement and the subsequent urbanization have had significant implications on agricultural activity. The rate and state of development provide an indication of the socio-economic and political goals of the respective societies as these are the underlying driving forces behind the activities that take place within a particular location.

Population growth is regarded in both academic and public domains to be occurring at a faster rate in the developing nations. As this takes place it is increasing the demand for crop land for commercial and subsistence agriculture to produce food, fibre and other materials for industrial purposes (Barbier, 1997). To meet the rising demands of the respective communities, farmers subsequently turn to agricultural extensification and intensification, through further land-cover alteration (Meyer & Turner II, 1992; Bilsborrow & Ogendo, 1992).

Agricultural extensification involves the expansion of land onto marginal areas. This is intimately connected to urbanization which creates urban-rural linkages (Lambin, 2001). The erecting of roads, bridges, and railroad routes increases the accessibility of people in peri-urban and rural areas into the more marginal landscapes where they are able to expand agricultural activity. Agricultural intensification involves raising the levels of inputs and output in value or quantity, of cultivated or reared products per unit area over a specified time frame (Meyer & Turner II, 1992; Gibson *et al.*, 2006). Notably, from 1961 to 1996, global food production doubled from a 10% increase in agricultural land use (Lambin *et al*, 2001). This trend has been documented to be consistent with the initiation by the Second World War policy of the 'plough up campaign' (Pattison & Lane, 2011).

The expansion of agricultural land has been necessary for sustaining communities, and some studies have documented little to no degradation as a result of the land use (Meadows & Hoffman, 2002). However, there are many other examples which have provided evidence of agricultural mal-practise as a regular occurrence, and in more extreme circumstances, known to lead to desertification owing to grievous pressure on the land (Meyer & Turner II, 1992; Lambin, 2001; Zaladis *et al*, 2002). The process is also documented to continue from one location to the next - when the land has outlived its usage. Such cases are more common in developing countries, where improper agricultural practices are still prominent (Lambin, 2001).

2.6 Flood intensifying conditions: the role of agriculture

2.6.1 Overview

Agricultural practices and the mismanagement of land are capable of increasing flood magnitude and occurrence (Pattison & Lane, 2011). This is generated by promoting soil degradation (Zaladis *et al*, 2002), damaging riparian ecosystems and altering riverine flow (Meyer & Turner II, 1992; Wang, 2004). The main reasons for this involve the failure to invest in sustainable land-use activities on the existing agricultural land (Barbier, 1997).

There are countless examples, which indicate that improper activities have had detrimental implications. Between 1945 and 1990, poor farming practices around the globe were reportedly responsible for the degradation of 20% of vegetated land in developing regions, as large population densities were located in areas that should not have been farmed (Barbier, 1997). This can be traced to historical policies, and colonial systems, such as those of Apartheid in South Africa, which amassed large numbers of people on small areas of land – thereby causing extensive damage (Meadows & Hoffman, 2002).

The poorest 20% of the rural population in developing countries are concentrated on lands with low potential for adequate agricultural output. This generally comprises the low quality marginal agricultural lands, where the rainfall is often low and in some instances unreliable (Barbier, 1997). The soil conditions tend to be poor and the topography also acts to hinder agricultural productivity; and this in turn increasing the likelihood of enhanced land degradation. For instance, studies by Arayer (2011) and Annaler (1984) in the Usambara Mountains in Tanzania, and in the Tigray Highlands of Ethiopia, indicated that high population densities and intensive agricultural activity on mismanaged agricultural land, had led to severe soil erosion and soil fertility deterioration as well as amplified surface runoff, particularly in the mountainous areas.

Agricultural practices are capable of leaving the land with irreversible effects and exposed to natural elements; both before planting and after harvesting, thereby promoting land erosion (Gholami *et al.*, 2010). In arid conditions where the land is bare, it becomes further baked and hardened making infiltration difficult and accelerating runoff (Cupido, 2005). In contrast, forested areas have naturally low levels of surface runoff and soil erosion (Annaler, 1984).

Excessive sediment load in runoff picked during erosion processes, caused by cultivation and trampling, are believed to be influential to stream destruction (Allan, 2004). In some locations, the implications of the increased sediment loads carried by runoff lead to siltation which in turn reduces channel depth, and raises discharge levels (Yin & Li, 2001).

2.6.2 Pastoral and arable agriculture as mechanisms for increasing surface runoff

Pastoral agriculture involves livestock farming. In this instance, the initial problem can be found with its general location. It tends to be carried out on what is viewed less arable land, which generally comprises the uplands of the catchment, where opportunities for crop production are limited (Chantalakhana, 1990; Pattison & Lane, 2011). Where livestock is managed appropriately, it generates returns which enable farmers to further invest in improving the quality of their land. On the other hand, inappropriate livestock farming may result in extensive land degradation (Chantalakhana, 1990). This problem is worsened as soils in these areas are generally more susceptible to degradation and erosion (Pattison & Lane, 2011).

The more immediate effects are determined by the weight of the animals and trampling which compact the ground surface thereby degrading the ecological status of the soil. Studies have been carried out documenting that sheep weighing 40kg exert a significant amount of pressure on the ground, subsequently minimizing infiltration capacity of the soil (Pattison & Lane, 2011; Udom *et al.*, 2011).

In addition, livestock are also known to graze or browse excessively, which then exposes the ground to overland flow, in the event of rainfall. Over and above all these problems, each is exacerbated by the documented "exponential increases in stocking numbers and densities (which have), been correlated with changing flood risk" (Pattison & Lane, 2011:79).

Similarly, the types of ploughing methods, and the extent to which these are practised, also influence the amount of precipitation converted to overland flow. This is in addition to their location within the catchment (Pattison & Lane, 2011). For example, terrace and contour ploughing that follow the natural slope contours enhance infiltration and water retention. However, situations where this is inappropriately practised will inevitably result in extensive runoff along slopes (Alexander, 1993).

The long-term implications of improper agricultural practice may also lead to desertification (Zha & Gho, 1997; Hawando, n.d.). Severely degraded ecosystems may be unable to rejuvenate; and they can become so redefined to the extent that there is little to no vegetation to retard overland flow. Inappropriate agricultural methods may also increase flood risk by encouraging encroachment by alien vegetation species (Richardson & van Wilgen, 2004). Encroachment by these species also transforms ecosystems, as alien plants use significantly larger amounts of water than indigenous species. This, the authors argue, hardens the ground, promotes erosion, and increases the likelihood and implications of fires through increased biomass (Euston-Brown, 2000). Moderate to severe fires are known to reach soil surface temperatures greater than 500°C (Ursino & Rulli, 2010), which then manipulates the soil characteristics. As vegetation cover is destroyed the chemical composition of plant elements is changed, and may water may transfer throughout the soil profile and condense in the cooler underlying layers. This subsequently forms a water-repellent layer at a deeper level, which restricts the infiltration of water, and causes overland flow, as well as erosion.

2.6.3 Ostrich farming as an environmental flood risk driver

While the negative implications of livestock rearing are most evident in ungulatory species (Udom *et al.*, 2011), this is applicable to all animals. Ostrich farming has been a lucrative industry in South Africa, having made a significant contribution to South Africa's economic and cultural development (South African Ostrich Chamber Biodiversity Unit, 2009; Reyers *et al.*, 2009). However, the long-term implications of the practice make it a very precarious activity in the context of land use and degradation. The rearing of ostriches is hyper-intensive; and it takes place all the year round (Herling *et al.*, 2008). As this provides limited time for vegetation recovery, some have questioned its sustainability as a long-term agricultural practice (Agriculture and Resource Management Council of Australia and New Zealand, 2000; Herling *et al.*, 2008). In addition to the sheer weight of the birds (often exceeding 100kg), which hardens the soil, further challenges to ground cover are found in the "restlessness, continual foraging, dust bathing and nesting activities" within the overstocked rearing camps of the Little Karoo (Le Maitre *et al.*, 2007; The Water Wheel, 2010: 30).

The abovementioned ostrich behaviour on natural vegetation may directly increase surface runoff, thus influencing flood occurrence in the Little Karoo. For instance, vegetation in the Little Karoo is important for water retention, as it promotes infiltration into the soil by reducing rain splash effect, hindering runoff, and providing debris to serve as erosion barriers (Coetzee, n.d.). It also creates a suitable habitat for biological soil crusts such as moss and lichen, that are necessary for the maintenance of healthy ecosystems (Le Maitre *et al.*, 2007), and require long periods to rejuvenate.

The floods which result, possibly attributable to agricultural activity, have implications on riparian zones, and catchments as a whole (Richardson *et al.*, 2007).

2.7 Climate change as a driver of future flood occurrence

Climate change is expected to have significant repercussions on ecosystems, and more specifically, vegetation dynamics around the Little Karoo (Karanja *et al.*, 2004; Meadows, 2006). With the current losses associated with floods around the Cape belt extending from Saldanha Bay through to Port Elizabeth, the prospect of more severe events that could accompany a changing climate has triggered the urgency for research and preparation. For instance, locations around southern Africa with increases in the variability and intensity of daily rainfall events have been assessed using General Circulation Models (GCM) (Joubert & Hewitson, 1997; Meadows, 2006). The results indicate that the climate is changing, and in the process the average annual rainfall and temperatures in South Africa will change over the course of this century (Midgley *et al.*, 2010; Nel *et al.*, 2011).

This 2010 study concurs with that of Midgley *et al.* (2005), who projected shifts in rainfall seasonality and patterns of extreme rainfall through increases in summer rainfall region in the interior, and towards the eastern flank of the Western Cape. They forecast that weaker frontal systems can be expected to the south, leading to less early and late winter rainfall events in the south-western Cape. The precipitation reduction is expected to range from 3% to 27%, and will probably be worse in the drier locations across the country (Erasmus *et al.*, 2000), thereby substantially compromising the agricultural sector which is currently allocated 62% of the available water resources (Midgley *et al.*, 2010).

The weaker rainfall onto the continent will result in "drier winters in the Western Cape (more so, further into the continent) as cold fronts could possibly be shorter in duration" (Midgley *et al.*, 2005:28; Midgley *et al.*, 2010). They further note that the systems could progress inland; rainfall could intensify in the mountainous regions and could potentially rejuvenate the groundwater systems of the Karoo, that are more dependent on extreme rainfall events than on the mean annual rainfall (Midgley *et al.*, 2005; Midgley *et al.*, 2010).

The consequences of a changing climate and a reduction in rainfall are much greater for the already arid areas, where vegetation dynamics are highly sensitive and significantly influence flood occurrence. By 2050, it has been forecast that between 51% and 61% of succulent Karoo and fynbos may be lost in South Africa (Karanja *et al.*, 2004; Meadows, 2006). However, such calculations do not consider the implications of poor agricultural practices, and land degradation, which are most prominent in the commercial farming areas of the Western and Northern Cape provinces (Gibson *et al.* (2005:12).

The challenge posed by arid areas becoming drier is that the ground will become even more compact. If rainfall intensifies in the mountainous areas (Midgley *et al.*, 2005; Midgley *et al.*, 2010), with less vegetation on the surface to restrict the overland flow, river discharges may peak more rapidly than they already do. Flooding may become less frequent owing to the shorter rainfall season, but potentially more dangerous as flash flooding would be more probable. These impacts could be further exacerbated as the results of modelled atmospheric CO_2 levels over South Africa indicate a doubling effect. This would increase the average annual runoff by 2%, and up to 8% in the mountainous areas of the south-western Cape (Midgley *et al.*, 2010). This excessive runoff may instigate major challenges for the agricultural sector in severe rainfall exposed areas, as increasing erosion causes a rise in the suspended sediment loads and river nutrients, ultimately degrading the quality of water used for irrigation.

2.8 Approaches to flood research

2.8.1 Overview of methods for flood calculation

As part of on-going and future flood hazard research, a number of methods are widely used across South Africa (Alexander, 2000). These incorporate both rainfall and basin characteristics. They are outlined in the South African Road Drainage Manual, which was developed by the South African National Road Agency Limited (SANRAL). The document is a comprehensive source of different methods used around southern Africa to study flood hydrology (SANRAL, 2007). It was first developed in Pretoria for civil engineering purposes in 1981; but it has been refined over the decades for the analysis of catchment areas (SANRAL, 2007). Six methods are described in the manual which are listed in Table 2.1. The United States Soil Conservation Service (SCS) and Run Hydrograph methods are excluded from the manual. However, these will be discussed below.

Table 2.1 Methods available for flood calculation: application and limitations. Source: SANRAL, 2007.

Method	Input data	Recommended maximum area (km^2)	Return period of floods that could be determined (years)
Statistical method	Historical flood peak records	No limitation (larger areas)	2 – 200 (depending on the record length)
Rational method	Catchment area, watercourse length, average slope, catchment characteristics, rainfall intensity	< 15	2 – 100, PMF
Alternative Rational method		No limitation	2 – 200, PMF
Synthetic Hydrograph method	Catchment area, watercourse length, length to catchment centroid (centre), mean annual rainfall, veld type and synthetic regional unit hydrographs	15 to 5000	2 – 100
Standard Design Flood method	Catchment area, slope and SDF basin number	No limitation	2 – 200
Empirical methods	Catchment area, watercourse length, distance to catchment centroid, mean annual rainfall	No limitation (larger areas)	10 – 100, RMF

Statistical methods

Statistical methods are used for determining the return periods for historical annual maximum flow or rainfall data (Jones, 1997:357; SANRAL, 2007:3-3), through "fitting of theoretical probability distributions" to the data (Van Bladaren *et al.*, 2007:5). Originally developed by the California Department of Water Works in the late 1800s (Makkonen, 2007), there are now over ten plotting positions which are used for calculating the probabilities for extreme events. Selected examples of widely used plotting positions include those of: Weibull (1939), Beard (1943), Gringorten (1963), Hazen (1914), Harris (1996), Cunnane (1978), and Kimball (1960) (Makkonen, 2005; Nadarajah & Shiau, 2005; Kay *et al.*, 2006; Buchele *et al.*, 2006).

For the purposes of flood estimation the more frequently used probability distributions include the Pearson Type 3 (P3), log-Pearson Type 3 (LP3), the log-normal (LN), the extreme-value distributions (EV) and the general extreme value (GEV) distribution (GEV) (Van Bladaren *et al.*, 2007). In South Africa, specifically, the LP3 and GEV have been found to be frequently used for the most part, of which Greenwood's 1979 approach is most common in the instance of the GEV (Van Bladaren *et al.*, 2007)

The outputs of the frequency analyses are reflected in the form of either the Annual Maximum series (AMS) or the Partial Duration Series (PDS) (Mkhandi *et al.* n.d.; Van Bladaren *et al.*, 2007). This approach depends on access to historical flood records in order to carry out calculations. However, in the absence of these, the data from comparable catchments adjacent to the area of study may be used instead (SANRAL, 2007:3-3).

Additionally, Kundewicz and Robson (2004) acknowledge the use of Exploratory Data Analysis (EDA) which they indicate is an advanced visual examination of data, and an important component of statistical analysis. "It involves using graphs to explore, understand and present data" (Kundewicz & Robson, 2004:9), and visual analysis to identify and interpret patterns, that can eliminate the need for a formal statistical approach.

The Rational Method

The Rational Method is directly based on the law of conservation of mass (SANRAL, 2007:3-3), where the simple formula ($Q=C_uC_iA$) relates the runoff-producing potential of the watershed, the average intensity of rainfall for a particular length of time (the time of concentration), and the watershed drainage area (Thompson, 2007). Rainfall intensity is a key input, and as uniform aerial and time distribution of rainfall are assumed, the method is only recommended for catchments smaller than 15 km^2 (Sinske, 2010). The outputs are limited to flood peaks and empirical hydrographs (SANRAL, 2007:3-3).

The Alternative Rational method has been adapted from its predecessor the Standard Rational method (SANRAL, 2007:3-3). However, while the Rational method uses the depth–duration return period diagram to determine the point precipitation, the Alternative method uses "the modified Herschfield equation, as proposed by Alexander, for storm durations of up to six hours, and the Department of Water Affairs' technical report TR102 for durations from one to seven days" (SANRAL, 2007:3-3).

The Unit Hydrograph Method

The Unit Hydrograph Method was one of the first tools available to the hydrologic community to determine the complete shape of the hydrographs rather than the peak discharges only (Bhunya *et al.* 2011). It is suitable for the determination of flood peaks as well as hydrographs for medium sized rural catchments ranging from 15 km^2 to 5000 km^2 (SANRAL, 2007:3-3). This method is based mainly on the regional analysis of the historical data; and it is independent of personal judgment. The unit hydrograph concept proposed for estimating the storm runoff hydrograph at the gauging site in a catchment corresponding to a rainfall hyetograph, is still a widely accepted and appreciated tool in hydrological analysis (Bhunya *et al.*, 2011).

Although regarded as reliable, problems of variability exist, as individual hydrological occurrences are lost through the regional divisions and averaging of the hydrographs. This must be done for catchments smaller than 100 km^2 (SANRAL, 2007:3-3). An additional development to this method is proposed in the Synthetic Unit Hydrograph method (Ramirez, 2000). The standard unit hydrograph method is associated with specific effective rainfall duration, while the 'synthetic' unit hydrograph expands on the rainfall-runoff data, to incorporate the catchment characteristics (Bhunya *et al.*, 2011; Ramirez, 2000).

The Standard Design Flood Method

The Standard Design Flood (SDF) method was developed to provide a uniform approach to flood calculations (SANRAL, 2007). It is an expansion of the rationale method applied, but applied with regionalised parameters, depending on the situation and the characteristics of the catchment (Sinske, 2010). The standardized discharge parameters are based on historical data; and these have been determined for 29 homogeneous basins in South Africa - with unique runoff coefficients and rainfall intensity (SANRAL, 2007:3-3; Sinske, 2010).

Empirical methods

The empirical methods are generally used where there are limited data, to determine the relationship between simple peak flow rates and catchment characteristics; and ultimately, to establish the general regional parameters (SANRAL, 2007:3-42). These methods require a combination of experience, historical data and the results of other methodologies used. They are commonly used in medium to large sized catchments greater than 100 km^2. As the data availability increases, these methods have either been improved, or replaced by other methods of hydrological analysis (SANRAL, 2007:3-42).

The SCS Method

The SCS method is a computer-based empirical hydrograph generating technique developed by the United States Soil Conservation Service. It was initially used for small farms and later applied to other land uses including urbanized and forested catchment areas (Soulis *et al.*, 2009). It is suitable for generating flood peaks and runoff volumes for catchments smaller than 10 km^2 and with slopes of less than 30 percent (SANRAL, 2007:3-3). This method takes into account most of the factors that affect runoff, such as quantity, time distribution, and the duration of rainfall, prevailing soil moisture conditions, changing infiltration rates over time, and the size and characteristics of the catchment (SANRAL, 2007:3-3). These make it more preferable to the rational method.

<u>The Run-Hydrograph Method</u>

The Run-Hydrograph method is another statistical method for the determination of floods. Like the AMS and PDS methods, it is also based on the regional historical data; but it is used less frequently. In this instance, hydrographs with the same return period, but different runoff volumes and peak discharges are calculated (SANRAL, 2007:3-3).

2.9 Geographic information systems for flood research

In addition to these well-established methods of flood estimation, geographic information systems have proved to be useful tools in flood-risk assessment. For instance, geospatial analysis tools such as Arcview and the Earth Resources Data Analysis System (ERDAS) (Bai & Dent, 2006; Reis, 2008), can provide valuable indications of land use and land-cover change, which influence the surface runoff, and floods. Through corroboration with remote sensing, in the form of satellite imagery and aerial photography, it is possible to carry out environmental monitoring schemes to determine the extent to which basin characteristics are changing (Bai & Dent, 2006; Reis, 2008).

This is particularly important for flood hydrology as it indicates the environmental status of the area where the precipitation is captured and recorded.

The first satellite, Landsat Multi-Spectral Scanner (MSS) was launched in the early 1970s, generating the earliest satellite images for commercial use (Tueller, 1989; Markham, 2004). This stimulated the significant development of satellite technology. Today, this is reflected in more than 40 global satellites providing measurements. For instance, Système Pour l'Observation de la Terre (Spot) 5 with a spatial resolution of 15m, Landsat Thematic Mapper (TM) of 30m, and, Landsat Enhanced Thematic Mapper Plus (Etm+) of 30m, all provide reliable indications of land-cover types and land uses, and they are generally available for research purposes (Helmschrot & Flugel, 2001, Yuan *et al.*, 2005).

Other satellites such as Ikonos (resolutions of 1 and 4 metres) provide finer detail. Unfortunately, these images are less accessible due to their higher costs.

There are cheaper and more readily available spatial images in the form of aerial photographs. Although these images have a lower spatial resolution than many satellite images, which limit the depth of observable ground cover, the level of detail is accurate enough to allow for analyses of large homogeneous land-cover types (Kadmon & Harari-Kremer, 1999). Furthermore, the value of aerial photographs ultimately lies in their temporal resolution which exceeds that of satellite images.

In South Africa, aerial photography may be used in combination with satellite imagery to examine trends of land-cover change, as the data dates back to the 1930s, for most parts of the country. The high spatial and temporal resolutions for most locations allow for comprehensive multi-temporal land-cover assessment. As this is particularly useful for research, aerial photography has always been recognized as an important source of information for studies related to vegetation dynamics (Kadmon & Harari-Kremer, 1999; Fensham & Fairfax, 2002).

Studies using aerial photography have been applied to different biomes across the globe. These range from glaciers, coastal, arid and semi-arid, savanna grasslands, to montane environments (Rossouw, 1997; Kadmon & Harari-Kremer, 1999; Fensham & Fairfax, 2002). Since the series of images extends for almost a century in history, this allows for a sound understanding of flood-prone environments, and fairly accurate projections of future vegetation cover changes in any particular location.

2.10 Conceptual and research frameworks that apply to the study

2.10.1 Overview

The conceptual framework illustrated in Figure 2.1 has been adapted from the conceptual model by Orr and Carling illustrated in Pattison and Lane (2011), which relates to the impacts of overgrazing on run-off and soil erosion. It was developed for the purpose of assisting the interrogation of two variables that are associated with flooding in the Kandelaars catchment: rainfall and land use/cover. The researcher acknowledges that the selected variables are dynamic with the ability to change spatially, temporally, and vary in intensity, and the framework guides the case study as such.

Other factors which affect floods such as soil types and groundwater rejuvenation have been excluded as they could not be assessed. Such research was determined to be beyond the scope of a coursework Masters thesis.

The relevance of the land-cover change and rainfall occurrence on the flooding is thoroughly discussed by Pattison and Lane (2011). The paper highlighted that more research required to determine which of the two variables has a stronger influence on flooding. The debate is even more precarious as climate change is affecting weather patterns around the globe in different ways, and these are only starting to be understood. Moreover, climate induced change for floods is difficult to determine as there is often problems with availability of appropriate data to use (as it is generally in short supply), methods to apply, and the interpretation of results (Kundzewicz, 2004).

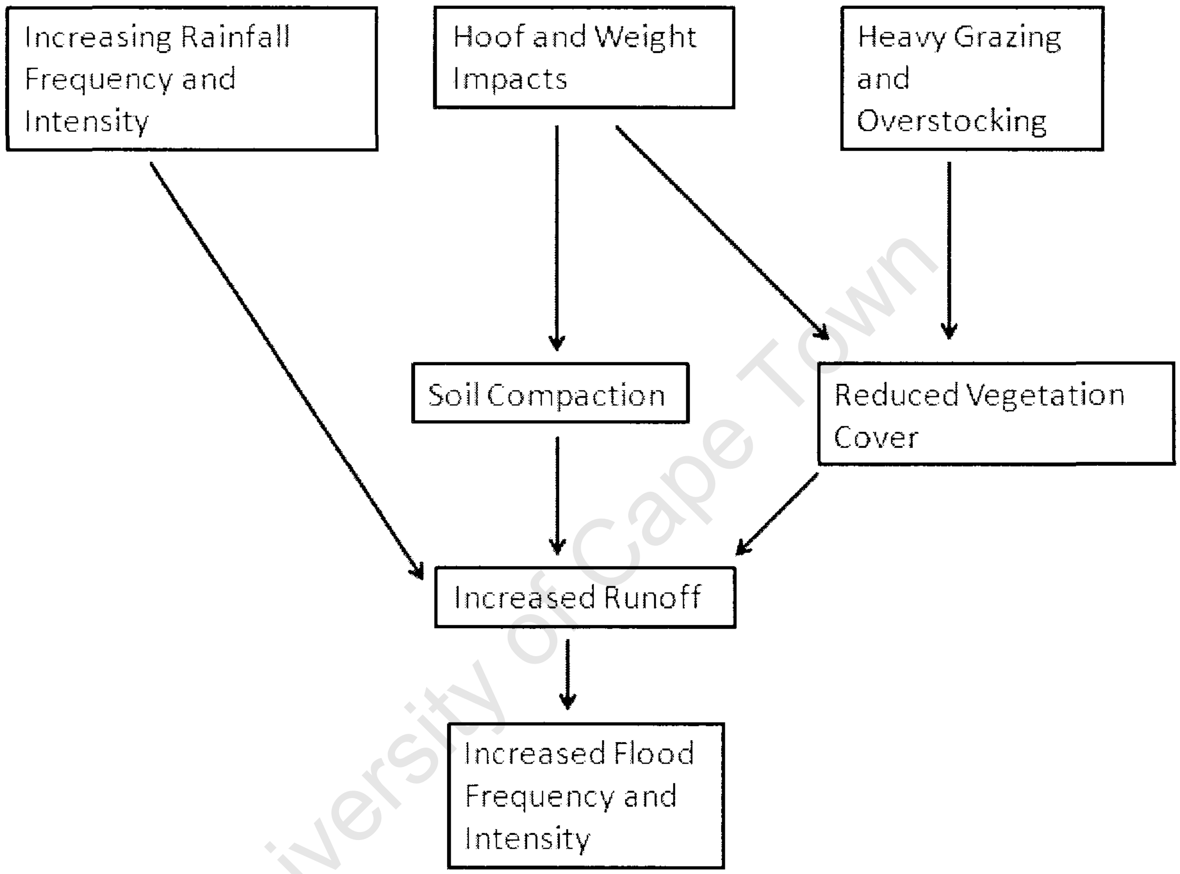

Figure 2.1: Conceptual framework illustrating rainfall occurrence and agricultural land use as drivers of increased flood frequency and intensity (adapted from Orr & Carling (2006) in Pattison & Lane (2011))

2.10.2 Research framework

The research framework demonstrates the relationships and variables that were assessed (based on available data), and also used to generate tools for the research of flooding in the Kandelaars catchment (detailed in sections 4.6.2 and 4.6.3). It incorporates the processes detailed in Figure 2.1 and their connection to the objectives for this study which are stated in Chapter 1.

The research aimed to assess the frequency and magnitude of the floods within the Kandelaars catchment which are defined by both rainfall events as well as basin characteristics (Kundewicz, 2004; Smith & Petley, 2009; Pattison & Lane, 2011). Consequently, to unravel the rate (pattern), and extent to which the two variables affect the frequency and magnitude of floods, statistical approaches were selected to assess rainfall and river discharge, and a time-series analysis was carried out for the land-cover assessment. This would allow the researcher to look for correlations between the variables.

Objectives	Method/Approach	Indicator
Investigate rainfall occurrence to identify possible changes in frequency, magnitude, and seasonality, of extreme rainfalls.	Annual Maximum Series	Return period of extreme rainfalls
	Exploratory Data Analysis	Temporal spread of extreme rainfalls
Examine river flow to identify possible changes in frequency and magnitude in extreme river flows.	Annual Maximum Series	Return period of extreme floods
	Partial Duration Series	Temporal spread of extreme floods
	Exploratory Data Analysis	
Explore changes in agricultural land use that may have an impact on flooding in the catchment.	Time series analysis using aerial photography and satellite imagery	Rate and quantity of land cover change
	Field visit (ground-truthing)	Extent of land cover change
Examine relationships between extreme rainfall occurrence and extreme river flows.	Exploratory Data Analysis	Proximity of rainfall and river flow extremes to each other

Figure 2.2: Research framework for the study

2.11 Summary

As this study sought to examine the flood drivers within the Kandelaars catchment in Oudtshoorn, this chapter introduced the major flood types that are associated with adverse flood impacts. Given the study's focus on flood occurrence in the Kandelaars catchment, particular emphasis was placed on the contributory role agriculture in increasing flood magnitude, including risk factors associated with ostrich farming. The chapter concluded by reviewing the flood determinants by SANRAL and by presenting a schematic framework linked to the study's research objectives and selected methods, and indicators, for implementing its research.

Chapter Three: The Research Context

3.1 Introduction

The geographic context for this study is the Oudtshoorn Local Municipality in the Western Cape Province of South Africa. The specific study area is the Kandelaars River catchment, which is situated south-west of the town of Oudtshoorn. The chapter gives an overview of the Oudtshoorn Local Municipality, including its location, areal extent, and the relative position of the Kandelaars catchment. It continues by describing the important climatic and topographic features that characterise the area, including the specific attributes of the Kandelaars catchment related to the occurrence of flash floods.

This is followed by an overview of the Oudtshoorn Local Municipality settlement and development history, including a description of ostrich farming around Oudtshoorn town, with a particular focus on its environmental impact, since this has increased surface runoff. The chapter concludes by describing the recent flood history of the area. As there is limited information specifically on the Kandelaars River, in this context chapter, information will be drawn from the immediate surrounding region.

3.2 Oudtshoorn location and extent: introducing the Kandelaars catchment

3.2.1 Location and areal extent

The Oudtshoorn Local Municipality is one of eight municipalities (see Figure 3.1) that comprise the Eden District in the Western Cape Province of South Africa. It incorporates the towns of Oudtshoorn, De Rust, Dysselsdorp and the surrounding rural areas, governing an area of approximately 9040 ha (Greater Oudtshoorn Municipality, 2006).

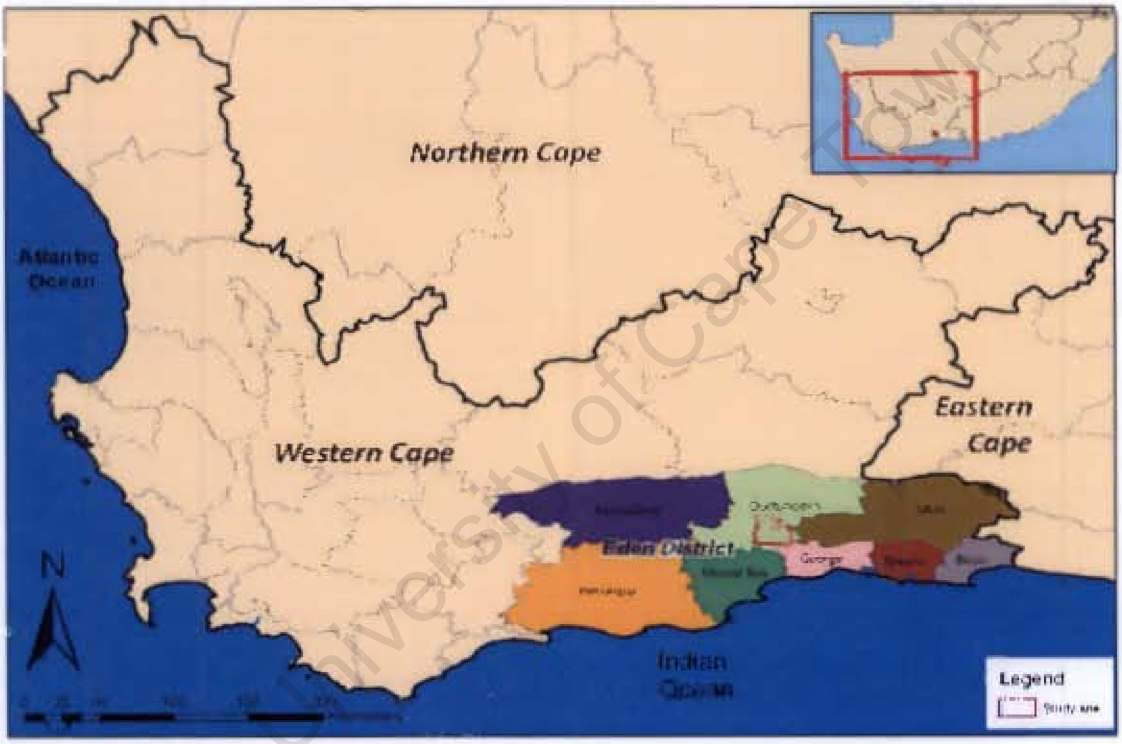

Figure 3.1: Map of the Eden District Municipality, Western Cape, showing the location of Oudtshoorn and the Kandelaars catchment
Source: Environmental Potential Atlas (ENPAT), 2002

3.2.2 Introducing the Kandelaars catchment

Specifically, the Kandelaars catchment, as displayed in Figure 3.2, is located 10 km south-west of the town of Oudtshoorn (at geographical coordinates 22° 13', 28.65" E; 33° 36', 10.79" S). It covers an area of approximately 400 km^2, with three rivers flowing through it. These are the Groot Doornrivier, the Kandelaars River and the Klein Doornrivier, all of which originate in the Outeniqua mountains at an altitude of over 1000m. They eventually combine into one river, the Groot Doornrivier, before draining into the Olifants River.

The Groot Doornrivier is the longest of these (28.2 km), with the latter two serving as its tributaries. The Kandelaars River and the Klein Doornrivier, respectively, extend to lengths of 14.15 km and 9.1 km (ENPAT, 2002).

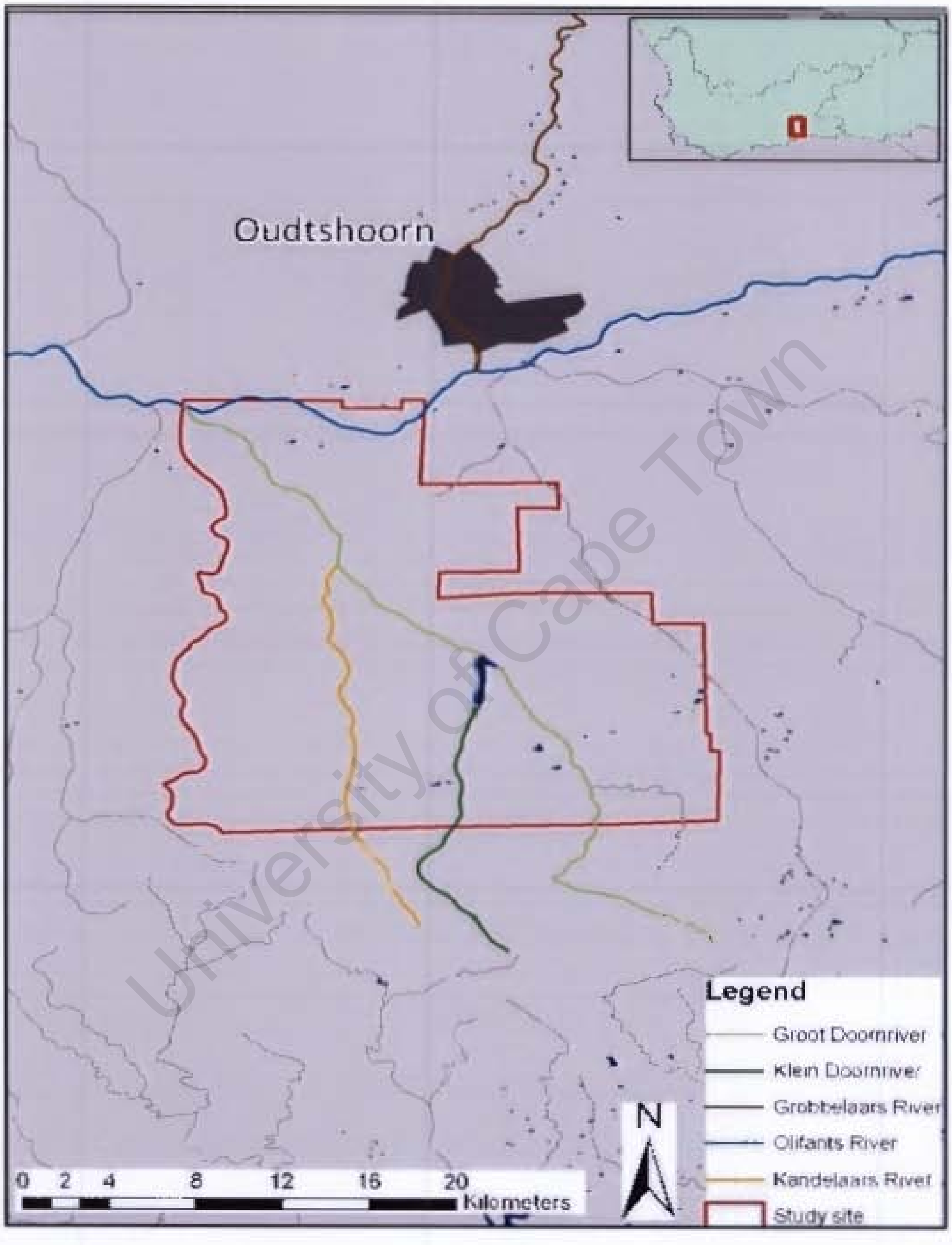

Figure 3.2: Rivers within the Kandelaars Catchment, Oudtshoorn. Source: Environmental Potential Atlas (ENPAT), 2002

3.3 Oudtshoorn: climate, topography and vegetation cover

The development profile of the Oudtshoorn Local Municipality, including its agricultural productivity and successful tourism industry, is significantly informed by the area's geographical profile, including its climate, vegetation cover and topography. These characteristics, which are described below for the broader region, are also relevant to the Kandelaars catchment, for which – as a smaller catchment – such specific data are not available.

3.3.1 Climate

The Oudtshoorn Local Municipality is surrounded by mountains; hence, it is largely characterised by orographic rainfall. Likewise, rainfall in the Kandelaars catchment is largely determined by the Langeberg-Outeniqua mountain ranges, experiencing precipitation ranges between 900 and 1600 mm per year on the upper slopes (Le Maitre *et al.*, 2009).

Winter rains are provided by mid-latitude cyclones (accompanied by cold fronts), and occasional cut-off lows, from the West. A cut-off low is developed when a mid-latitude cyclone is severed from the main planetary system (DiMP, 2010). Upon formation, the system loses momentum and either sits over a location, or moves along slowly, before dissipating. Owing to the strong atmospheric instability and convective updrafts, the system is capable of causing torrential rain. This often leads to floods and violent winds (DiMP, 2010).

Summer rainfall is also provided, from the east, via convective systems. However, these are less affected by the orographic gradients (Le Maitre *et al.*, 2009).

The town of Oudtshoorn is located within a basin, in a rain shadow; and it receives markedly less rainfall (Geldenhuys, 1997). The average annual rainfall ranges from

600mm to 800 mm; and these figures can reportedly drop to 100mm (Le Maitre, 2008).

Minimum and maximum mean daily temperatures range between 14°C and 22°C in winter, and 21°C to 31°C in summer. However, the municipality is prone to extreme temperatures; and these can range from -2.1°C to 46.6°C (Geldenhuys, 1997; Vlok & Yeaton, 2000). Maximum temperatures are documented to have increased by about 1°C over the last century; and "climate models predict this trend will continue over the next 40 years, with a further 1.2°C increase in maximum winter temperatures expected by 2040" (Nel *et al.*, 2011:3).

3.3.2 Vegetation profile

The Oudtshoorn Local Municipality is situated within the Cape Floristic Region (Gallo *et al.*, 2009). As is frequently found in other arid to semi-arid ecosystems, the vegetation profile depends on local rainfall patterns, including the intensity and frequency of the various rainfall events (Le Maitre *et al*, 2007).

The vegetation profile in the upper Kandelaars River catchment includes mountain fynbos, false fynbos, and mountain renosterveld (Vlok & Yeaton, 2000; Watson *et al.*, 2005; Vlok & Schutte-Vlok, 2010). This gradually changes with decreasing elevation into grassier shrubland, namely renosterveld, succulent Karoo, and sub-tropical thicket on the more fertile lower slopes (Le Maitre *et al*, 2007; Vlok & Schutte-Vlok, 2010).

The succulent Karoo habitat, located in the lower valleys, is also noted for its prominent features, known as *heuweltjies*. These are slightly raised circular features capable of reaching up to 40 m in diameter, which develop over buried termite nests (Le Maitre *et al*, 2007). As these contain humus that has accumulated over decades (if not millennia), they are highly fertile, and able to absorb large amounts of water (Le Maitre, 2008). These characteristics make the *heuweltjies* very succulent, and thus attractive food for livestock (Vlok & Schutte-Vlok, 2010).

Within the riparian zones, especially where the natural cover has not been altered by human activities, river banks and floodplains support reed beds or trees, and herbaceous shrubs (Le Maitre *et al*, 2007). The vegetation is dominated by large trees, such as *Acacia Karoo*, *Rhus lancea* and *Olea europaea africana* (Watson *et al.*, 2005). Due to the closer proximity of riparian vegetation to water bodies than that of the surrounding arid environment, it provides important resources for both wild and domesticated animals. These include sheep, cattle, and ostriches (Le Maitre *et al*, 2007).

In addition to the indigenous vegetation, the Little Karoo is reportedly host to several alien invasive plant species. These can have serious adverse consequences on local ecosystems, including increased risk of severe depletion of the groundwater, and an increased likelihood of fires. Records at the Gamkaberg Nature Reserve, which lies 33 km south-west of Oudtshoorn on the western flank of the Kandelaars catchment, indicate that the area is fire-prone, with the mean fire interval estimated at seven years (Watson *et al.*, 2005).

The severity of the fires is largely determined by the fynbos vegetation, which is naturally fire prone. However, the intensity is also enhanced by the alien vegetation. The invasive alien plant species of particular concern comprise the *Acacia mearnsii, Pinus* and *Populus* species and *Arundo donax* (Le Maitre, 2008).

3.3.3 Geological and hydrological profile

The Oudtshoorn basin, composed of hills of Cretaceous conglomerates, is a large semi-arid, low-land area found between the Swartberg, Rooiberg, Outeniqua and Kammanassie mountains (see Figure 3.3) (Geldenhuys, 1997). Tectonic activity extending 278 million years ago (Mya) has affected the Cape Supergroup rocks. This has resulted in the formation of the mountain chain known as the Cape Fold Belt (Shone & Booth, 2005), whose "backbone" is formed by the Swartberg and Langeberg ranges (Tankard *et al.*, 2009).

The basin itself is filled with sediments of Jurassic to Cretaceous age (from 199 to 65 Mya) resting on a base of the Cape Supergroup rocks (Shone & Booth, 2005; Booth, 2009). Underlying rock formations are of Table Mountain quartzite and shale, and Bokkeveld shale and sandstone, accompanied by Mesozoic sediments preserved in fault-bounded basins (Shone & Booth, 2005; Watson *et al.*, 2005).

The soils of the area, which are determined by the characteristics of the rocks, are composed of silicic soils and lithosols derived from quartzitic sandstones located all along the Western Cape region (Fey, 2010). The soil is poor in nutrients, shallow, acidic, and sandy (Vlok & Yeaton, 2000). While sandy soils typically have a high infiltration capacity, this is reduced in the upper catchment around Oudtshoorn, such as the Kandelaars, where the steep topography promotes runoff (Merz & Bloschl, 2009; Fey, 2010).

In comparison, soils located on the valley floor are reportedly deep, fine textured and of saline composition, with some islands of acidic white quartz (Merz & Bloschl, 2009). Where these valley soils have been protected against trampling by domestic livestock, roads and tracks, they possess a biological soil crust comprising cyanobacteria, lichens, and mosses (Le Maitre *et al*, 2007).

Water supply in Oudtshoorn is determined by approximately twenty perennial rivers, including the Olifants River (ENPAT, 2002). Although the area is categorized as an arid to semi-arid environment, river names such as the Olifants River (Elephant's River), and Moeras River (Marsh River), suggest that the perennial rivers once supported fertile wetlands, which accommodated buffalo, elephant, and hippopotamus (Le Maitre *et al.*, 2007).

Groundwater recharge is reportedly good in rainy years, due to the jointing and fracturing in large areas of the mountainous outcrop; however, subterranean storage ability is reportedly low (Smith, n.d.). In addition, the groundwater supply is often saline, owing to the geological formations, which form most of the aquifers. This gives rise to naturally saline groundwater; and when combined with the high evaporation rates, this makes the water naturally poor for agricultural purposes (Le Maitre *et al.*, 2009).

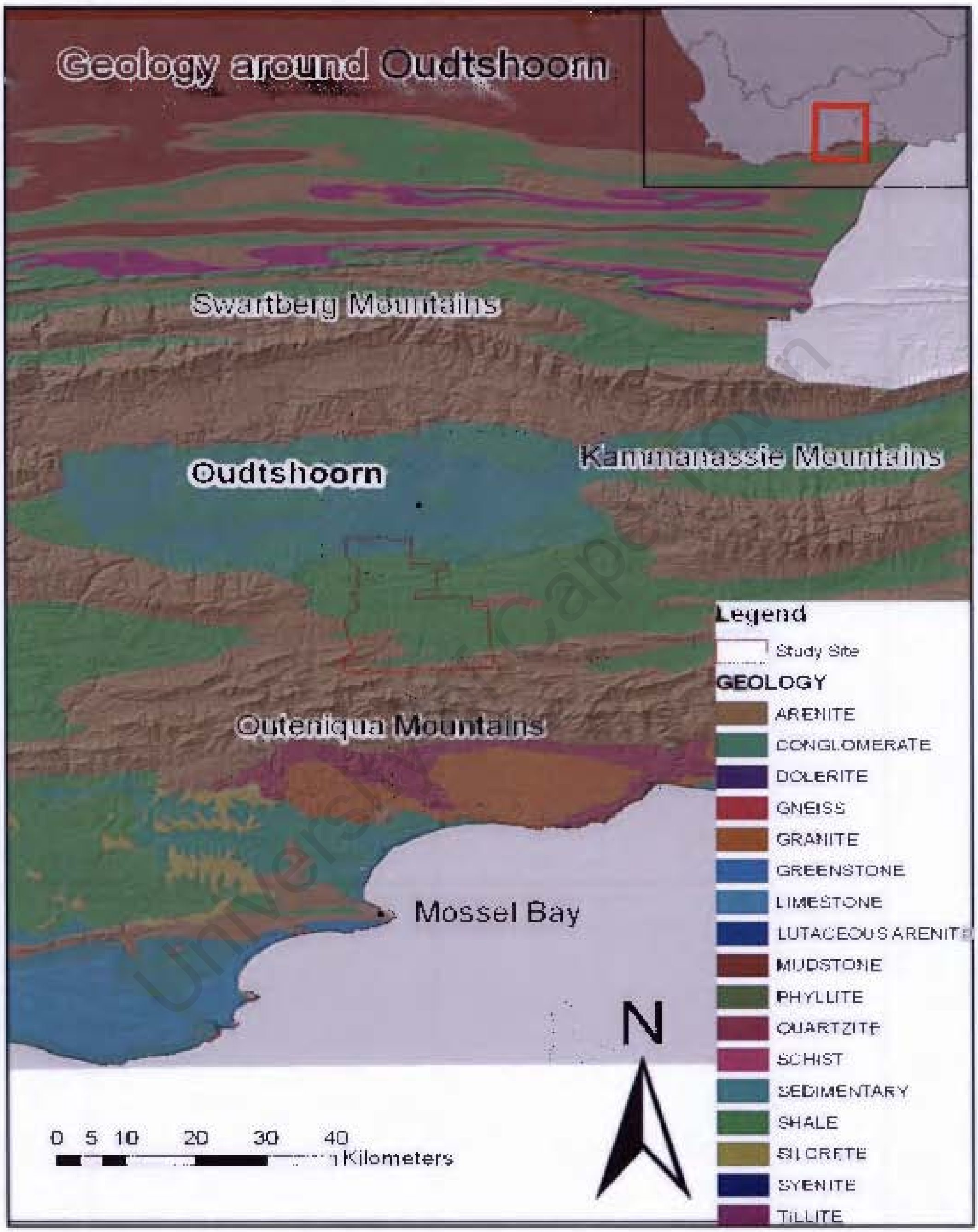

Figure 3.3: Geological profile of Oudtshoorn showing the location of the Kandelaars catchment Environmental Potential Atlas (ENPAT), 2002

3.4 Oudtshoorn Local Municipality: settlement and developmental history

The patterns of settlement and developmental history of Oudtshoorn Local Municipality have been determined largely by the geography of the region. Historic evidence acquired from the Boomplaas Cave, 30 km north of Oudtshoorn town, indicates that settlement in the area dates back to the second century A.D. This is when the occupation consisted largely of ancestral Hottentot herders (Deacon *et al.*, 1976).

European settlers reportedly arrived in the early 1800s, bringing farming activities, which led to browsing and overgrazing (predominantly by ostriches, but also sheep and goats) of dry lands, and the cultivation of alluvial areas (Reyers *et al.*, 2009). These activities also resulted in significant hydrological and vegetation changes over large areas of the Little Karoo (Le Maitre *et al*, 2007; Reyers *et al.*, 2009).

From the 1870s onward, the development of Oudtshoorn was closely intertwined with the ostrich farming industry. The ostrich industry expanded rapidly following the invention of the artificial incubator for ostrich eggs in 1869 by Arthur Douglas (South African Ostrich Business Chamber Biodiversity Unit, 2009).

Subsequently, by the early 20th Century, ostrich feathers were the fourth largest export commodity for the country (South African Ostrich Business Chamber Biodiversity Unit, 2009). However, following severe droughts in 1915 and 1916, the ostrich feather industry collapsed (Herling *et al.*, 2008). The industry's vulnerability to rainfall variability signalled the need for local water storage. This was provided in the form of the Kammanassie Dam in 1923, with a reservoir capacity of 35,870,000m^3 (Forde, 1925; Basson & Rossouw, 2003; DWA, 2010).

Its contribution towards irrigation schemes along the Olifants River resulted in a cycle of local agricultural expansion that then generated increased profits – allowing for further irrigation and subsequent growth of the agricultural sector (Forde, 1925).

Soon this economic growth would mean that there was more demand for water; and this led to the commissioning of the Stompdrift Dam in 1965 (see Figure 3.4).

This dam is larger than its predecessor, with a reservoir capacity of 55,300,000m^3, (DWA, 2010). Lastly, there is the smaller Koos Raubenheimer Dam situated north of Oudtshoorn town. Unlike the Kammanassie and Stompdrift Dams, which cater for agriculture, the Koos Raubenheimer Dam supplies water primarily for consumption by the town. Its capacity is reportedly a fifth of that of the Stompdrift dam (DWA, 2010).

While the history of the Oudtshoorn Local Municipality is significantly linked to ostrich farming, more recent development is the result of eco-tourism (Basson & Rossouw, 2003; O'Farrel, 2010). For instance, in 1974, the Gamkaberg Nature Reserve, located 33 km south-west of Oudtshoorn town, was established – in order to conserve a local population of endangered Cape mountain zebra and their natural habitat (Cape Nature, 2010).

Today the local tourism industry includes tours of natural and cultural features, such as the Boomplaas and the Cango caves.

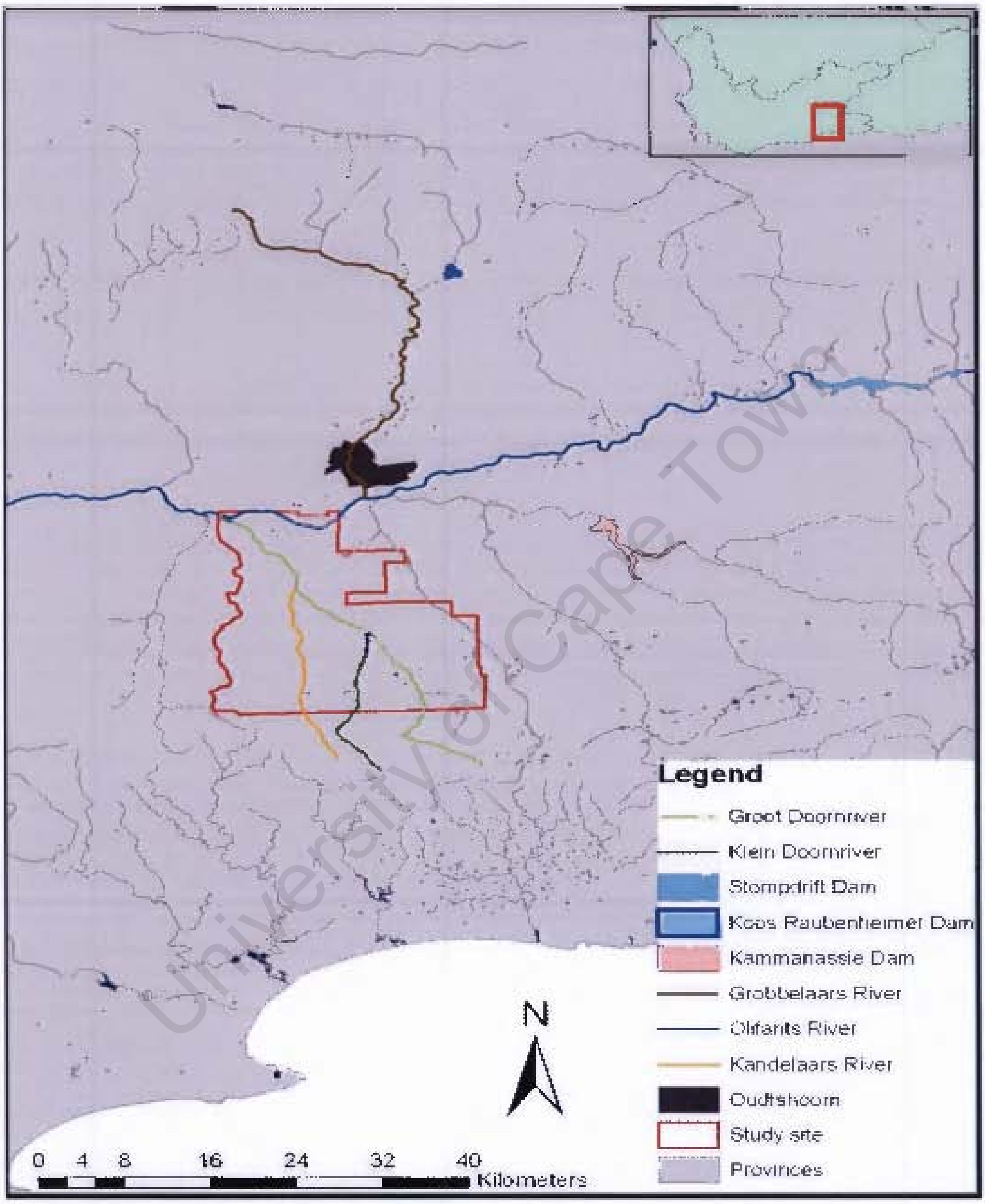

Figure 3.4: A display of the hydrological profile surrounding Oudtshoorn. Source: Environmental Potential Atlas (ENPAT), 2002

3.4.1 Current socio-economic profile

The population in the Oudtshoorn Local Municipality has remained constant over the past 20 years at approximately 80,000 inhabitants (StatsSA, 2010), with the current population comprising 6,963 black, 60,703 coloured, 476 Indian/Asian, and 11,462 white residents (Greater Oudtshoorn Municipality, 2006). It is further estimated that women and children account for 81% of the population, while the main languages spoken are Afrikaans, isiXhosa and English (Greater Oudtshoorn Municipality, 2006).

Although Oudtshoorn accommodates the highest concentration of ostriches in the world (Lamberchts *et al.*, 2004), agriculture contributes less than 5% of the area's employment (Greater Oudtshoorn Municipality, 2006). In 2007, the municipality recorded the fourth largest economy in the Eden District; and this can be attributed to community, personal and social services (26%), business and financial administration services (16%), manufacturing (13%), the retail trade, catering and accommodation (20%) (Oudtshoorn Municipality, 2010).

Agriculture, forestry and fishing contributed 9% to the local economy (Oudtshoorn Municipality, 2010). The current value is documented to be worth R1.18 billion, with a calculated annual growth rate of 3.6% (Nel *et al.*, 2011). However, despite this wealth and development, extreme poverty in the municipality has also been documented to be increasing – with an estimated 40% earning no income, and heavy dependence on social grants (Nel *et al.*, 2011).

3.5 Land use in the Oudtshoorn Local Municipality: adverse environmental consequences of ostrich farming

Within the inland municipalities of the Eden District, dominant land uses include agricultural crop and livestock farming (Reyers *et al.*, 2009). Livestock farming includes cattle, sheep and goat farming; however, specifically in the Oudtshoorn Local

Municipality, ostrich farming constitutes 75% of all agriculture (Greater Oudtshoorn Municipality, 2006; Hoffman *et al.*, 2009a).

The expansion of irrigated agriculture in the Oudtshoorn Local Municipality over the past century has allowed for economic development for the municipality through agri-tourism. However, the contribution of intense ostrich farming, in addition to extensive agri-tourism in the area, has resulted in marked environmental damage, including loss of biodiversity (The Water Wheel, 2010).

South Africa is estimated to have at least 580 registered ostrich export farms, with more than 450 of these farms being located in the Oudtshoorn Local Municipality (South African Ostrich Chamber Biodiversity Unit, 2009). Most of these farms practise flock breeding, where a flock of ostriches is placed on natural veld to breed (Wessels, 2003; The Water Wheel, 2010).

3.5.1 Environmental impacts associated with ostrich farming

Despite the wealth generated, significant adverse environmental impacts of long-term ostrich farming are well documented (Herling *et al.*, 2008; South African Ostrich Chamber Biodiversity Unit, 2009; O'Farrel, 2010; Coetzee, n.d.). For instance, soil erosion from roads and tracks are common features from the long-term rearing of these birds (Cupido, 2005). Additionally, there is severe degradation related to feeding activities and territorial behaviour, which include trampling on the ground.

A common feature is that vegetation is removed by ostrich activity within a radius of 50 m from containers, where supplementary feed is provided for the birds (Le Maitre *et al.*, 2007). The birds compact the soil, increasing the risk of erosion by both wind and water, ultimately destroying any future agricultural and economic potential that the land may have (Herling *et al.*, 2008; South African Ostrich Chamber Biodiversity Unit, 2009).

In addition, ostriches have more intensely grazed *heuweltjies* than other surrounding vegetation (Le Maitre *et al.*, 2007), and although feeding activities play a role in degradation, it should be noted that the natural vegetation within the Little Karoo is generally considered to be of poor nutritional value (Lamberchts *et al.*, 2004; The Water Wheel, 2010). Unlike cattle and sheep that rely on the natural environment for their nutritional needs, the birds are given specific breeder diets, which predominantly comprise lucerne (Herling *et al.*, 2008).

Farmers are more concerned with the space component of the carrier or habitat function of ecosystems (Herling *et al.*, 2008). This has led to overstocking of the birds; and subsequently, the sheer ostrich densities are another major factor causing extensive degradation. Where spaces should cater for one ostrich per 23 hectares, numbers are often 30 times what they should be – in order to maintain the profitability of the business (Herling *et al.*, 2008; The Water Wheel, 2010).

The continuous removal of vegetation from stream banks, and protective cover from riparian zones, leads to negative environmental outcomes – including degraded ostrich feeding camps, gulley and rill erosion.

3.5.2 Strategies to minimize environmental damage from ostrich farming

The acknowledgment of the adverse environmental impacts, by the ostrich industry itself, has led to adoption efforts to minimize damage at farm and district level. For instance, flock breeding is actively promoted, where farmers generally use a 'three-camp system' covering an area of 300 hectares (Herling *et al.*, 2008). For each of the camps, the ostriches are placed inside for eight months, removed for the next four, and then moved to the next in the following season (The Water Wheel, 2010).

The rotation attempts to allow each camp to rest and rejuvenate over a period of two years. An example is provided in Figure 3.5 below. While this represents a proactive strategy, it is constrained by inadequate rejuvenation periods for re-growth and lack of rainfall for vegetation growth. Consequently, the activity is deemed to be a non-sustainable agricultural practice (Herling *et al.*, 2008).

Figure 3.5: Example of three camp farming system. Source: Field visit, March 2012

Two methods of rehabilitation have been attempted (The Water Wheel, 2010; Coetzee, n.d.). The first method involves digging holes – with the intention that they should trap water through the use of a pudding plough. The second method employs the use of a track-drawn ripper to break the soil surface, thereby allowing for water retention and root penetration of plants (Coetzee, n.d.).

Unfortunately, the long-term implementation of these procedures is hindered by the recession that the industry is facing. Thus farmers tend to opt for the more viable rotation method, directing their resources towards matters requiring more urgent attention.

Other reserved approaches towards land rehabilitation have been attempted by Cape Nature through the Stewardship Programme, which involves conservation measures implemented on privately owned land (South African Ostrich Business Chamber Biodiversity Unit, 2009). However, the effectiveness of the process is challenged, since most farmers do not keep a regular record of the condition of their land, and there seems to be a general lack of interest (Cupido, 2005).

There is consensus that critically endangered areas around the Oudtshoorn Local Municipality require urgent soil stabilization and preventive measures to be implemented to reduce soil loss, as well as water and wind erosion (Cupido, 2005; South African Ostrich Business Chamber Biodiversity Unit; 2009; The Water Wheel, 2010; and Coetzee, n.d.). Rehabilitation in an arid area is slow, requiring a lot of time and recurrent check-ups to ensure that the required measures are carried out, as planned. The costs of such measures have been shown to be most prohibitive (Herling *et al.*, 2008).

3.6 Eden District flood profile

3.6.1 Significant flood history

Broadly, the region is prone to flooding, which is documented back to 1847 (Tempelhoff *et al.*, 2009). These events are attributable to the precarious meteorological characteristics, topography and the land uses of the area (Le Maitre *et* *al.*, 2007). These floods have consistently been recorded in George and Knysna (1916, 1932, and 1976) (Tempelhoff *et al.*, 2009).

Over the decades, settlements in the Eden District, and subsequent developments, have increased the exposure of people to severe weather and associated flood events. For instance, in 1981, one of South Africa's most tragic floods occurred in Laingsburg, just 200 km north-west from the town of Oudtshoorn (Alexander & Roberts, 1981; Alexander, 2000; WAMTechnology, 2011). The S.A. Weather and Disaster Information Service (SAWDIS) documents that excessive rainfall on a hardened catchment resulted in rapidly peaking flow of the adjacent Buffels River, making the discharge four times greater than any flood the town had ever experienced before (SAWDIS, n.d.).

A total of 103 fatalities were proclaimed, and of the 196 declared missing, 56 were never found (Laingsburg Municipality, n.d.). One hundred and eighty-four houses were destroyed, and only twenty-one remained. Other buildings that survived, but were badly damaged included churches, the magistrate's court, the post office and the hospital (SAWDIS, n.d.; Laingsburg Municipality, n.d.).

3.6.2 Recent flood losses

Over the past decade, the Oudtshoorn Local Municipality has sustained significant flood damage (economic and fatalities), most notably in 1996, 2006 and 2007 (Cape Argus, 1996; DiMP, 2010). The latter floods were both associated with cut-off low systems. In 2007, the cut-off low recorded downpours of 297mm of rainfall in George, in one day, and cumulatively more than 450mm of rain over three days (DiMP, 2010). Similarly in 2006, the cut-off low that caused significant damages in Oudtshoorn recorded 230mm of rainfall in George over a 24-hour period (DiMP, 2010).

The losses incurred by the November 2007 flood are particularly significant, as these totalled R96.7 million, respectively. The third highest direct costs were consolidated at a municipal scale. As much as R70.9 million (73.4%), and R22.8 million (23.6%) of these losses, were carried by provincial roads and the agricultural sectors, respectively (DiMP, 2010).

3.6.3 Other related risks

In addition to recurrent floods, Oudtshoorn experiences wildfires, livestock illness, and periodic droughts. The last, specifically, includes events from 1924–1925, 1927–1929, 1949, 1969–1970, 1978–1979, and most recently in 2009, which is regarded as possibly the worst the area has experienced in 100 years (Hoffman *et al.*, 2009b). Moreover, a severe outbreak of avian influenza occurred during the course of this study, which affected the accessibility to the farms, as many of these were closed.

By early June 2011, the outbreak necessitated the culling of close to 20,000 birds, which affected about 50,000 industry-related jobs countrywide (Cape Times, 2011; Business Day, 2011).

A similar outbreak in 2006 resulted in 26,000 birds being slaughtered at a cost of R600 million to the industry (The Gremlin, 2011).

3.7 Summary

This chapter has presented the biophysical and socio-economic context relevant to the Kandelaars river catchment. It has further demonstrated the vulnerability of the area, and specifically the town of Oudtshoorn, to flooding. The area is located in a rich biome that has enabled significant development, particularly through ostrich farming. This form of agriculture has been particularly useful in generating livelihoods for the area; but in the process has also been responsible for major degradation. The chapter concluded by briefly presenting the flood history of the region and other risks associated with the Oudtshoorn.

Chapter Four: Methods

4.1 Introduction

This study has sought to investigate and explain changes in flood magnitude within the Kandelaars catchment, evidenced by observed changes in river flow from 1982 to 2008 and by way of the data from different sources. These include daily rainfall records, as well as the river-flow data for the Kandelaars River. Due to this project's specific focus on the contributory role of land-cover on surface runoff, it was also necessary to examine the aerial photographs and the satellite images taken over time for the Kandelaars catchment.

This chapter begins by providing an overview of the methods used, their rationale and sequencing. It continues by describing the measures taken to compile and consolidate aerial photographs, as well as the relevant rainfall and river-flow data. The chapter concludes by presenting the analytical methods used to determine changes in land use and land-cover, as well as flood magnitude.

4.2 Overview

This project has comprised a case study of the Kandelaars catchment in the Oudtshoorn Local Municipality, an area that has reportedly seen increasing flood losses in recent years (DiMP, 2010). The study recognised that rising flood losses in the municipality could be attributed to many causes. These include the expansion of agricultural and tourist activities, which increase the number and value of the assets exposed. However, the scope of this research was limited to investigating the recent changes in the character of the flood hazards in the Kandelaars catchment.

In this context, the study examined two factors that affect flood hazard characteristics: rainfall and land-cover.

Prior to the study, it was unclear whether the recent damaging floods should be attributed to changing patterns of intense rainfall, or to catchment conditions, or a combination of both of these factors. This research applied a disaster-risk lens to investigate these questions.

The study's cross-disciplinary methods used to examine the Kandelaars' changing flood profile were not drawn exclusively from flood hydrology, although rainfall and stream-flow data were collected and analyzed. A time-series analysis of land use and land-cover was also undertaken, in combination with ground-truthing. This recognised the relationship between hardened catchment conditions and increased surface runoff (Gholami *et al.*, 2010; Pattison & Lane, 2011; Posthumus *et al.*, n.d.).

Secondary data and analysis methods were complemented by the primary data collection in Oudtshoorn, along with a review of the published and unpublished reports of recent floods in the area. The research process took place over seventeen months, from October 2010 to March 2012; and it comprised several clear stages. These are listed in Table 4.1.

Table 4.1: Outline of the research process

Research Process		
Research Focus	Purpose	Method
Scoping August - October 2010	Identification of flood prone area	Consultion with DiMP staff and Department of Agriculture
	Checking the availability of data to carry out study	Consultation with SAWS, DWA, and of flood records in published and unpublished articles
Secondary Data Collection October - November 2010	Rainfall data	Acqusition of rainfall data from the SAWS
	River flow data	Acqusition of riverine discharge data from the DWA
	Land cover data	Acquisition of aerial photography and satellite imagery from the CD:SM and CSIR
Secondary Data Consolidation and Analysis December - May 2011	Rainfall and river flow analysis	Application of AMS and PDS (software package used: Microsoft Excel)
	Land cover change analysis	7 year time series analysis (software packages used: Adobe Photoshop CS3 and ArcGIS 9.2)
Primary Data Collection June 2011 and March 2012	Qualitative data collection	2 key informant interviews
	Field visit (ground-truthing)	Farm visits around the Kandelaars catchment
Primary Data Consolidation and Analysis June 2011	Organization of information into themes	Descriptive application of qualitative data

4.3 Site selection

The rationale underlying the selection of the Kandelaars River catchment in Oudtshoorn was motivated by several factors. Firstly, flood-related agricultural losses in Oudtshoorn, as a whole, have reportedly increased (DiMP, 2010). The particular focus on the Kandelaars catchment was brought about by an informant from the Ministry of Agriculture. The scale of loss for the area suggested the need for context-specific research to inform on the subject of flood-risk management.

Secondly, this area has been noted for intense ostrich farming since the 1860s; and this type of farming is acknowledged to be environmentally damaging (South African Ostrich Business Chamber Biodiversity Unit, 2009). Thirdly, the topography of the surrounding catchment constitutes mountainous, steep land – with very shallow and stony soils (Merz & Bloschl, 2009; Fey, 2010).

These result in rapid soil saturation, making the location prone to rapid overland flow during heavy rainfall (Foody *et al.*, 2004). In addition, for the purposes of a Master's research project, it was possible for the researcher to source adequate rainfall, river-flow and land-cover records for the area, along with recent information on documented flood losses.

4.4 Data collection

Both secondary and primary data sources were used in this study to characterise the flood hazard within the Kandelaars catchment.

4.4.1 Secondary data collection

Given the study's focus on changing flood occurrence within the Kandelaars catchment in relation to rainfall and land-cover change, secondary data sources were, consequently, used in this study. These are listed in Table 4.2.

Table 4.2: List of the secondary data sources

Second Data Sources			
Data Source	Data Type	Rationale	Date
Quantitative			
Chief Directorate Surveys and Mapping	Aerial photographs	Temporal and spatial changes in land cover	1939-2008
Global Land Cover Facility	Landsat ETM+ satellite image		2001
Council for Scientific and Industrial	SPOT 5 satellite image		2008
South African Ostrich Business Chamber Biodiversity Management Unit	Shapefiles of Ostrich farms in Oudtshoorn	Location of ostrich farms in Kandelaars catchment	2007
South African Weather Services	Rainfall records	Intensity, frequency, and seasonality shifts in extreme rainfall	1926-2008
Department of Water Affairs	River flow data	Intensity, frequency and seasonality shifts in extreme discharges	1969-2008
Qualitative			
Cape Times and Cape Argus	Newspaper articles	Identification and examination of post-disaster flood losses	1996-2008
Disaster Mitigation for Sustainable Livelihoods Programme, the African Centre for	Published and unpublished resources and documents		2010-2011

<u>Aerial photographs</u> for 1939, 1964, 1968, 1974, 1985, 1991 and 2006, of the Kandelaars catchment, were provided by the Chief Directorate: Surveys and Mapping (CD:SM) located in Rhodes Avenue, Mowbray, Cape Town.

Landsat ETM+ 2001 satellite image was sourced online from the Global Land-cover Facility (GLCF). This is a NASA-sponsored venture located at the University of Maryland in the United States.

Spot 5 2008 image and **2007 shapefile of farm boundaries** were acquired from the Council for Scientific and Industrial Research (CSIR) based in Pretoria.

Ostrich farm spatial boundary data were acquired from the South African Ostrich Business Chamber Biodiversity Management Unit.

Daily rainfall records were obtained from the South African Weather Services (SAWS) for the two stations situated in the catchment. Rainfall records from 1926 to 2008 were collected for the Groot Doornrivier station, and from 1940 to 2008 for the Ruitersberg station (see Table 4.3 and Figure 4.1).

River-flow data from 1969 to 2008 were downloaded from the Department of Water Affairs' online database (see Table 4.3 and Figure 4.1)

http://www.dwaf.gov.za/hydrology/CGIBIN/HIS/CGIHis.exe/StationInfo?Station=J3H017

Table 4.3: Hydrological stations located within the Kandelaars catchment

Data Type	Station (site)	Location	Record Length	Measurement	Source
Rainfall	Groot Doornrivier (0028407 5)	33.7970S 22.2480E 442 m	1926 to 2009	millimetres (mm)	SAWS
Rainfall	Ruitersberg (0028083 3)	33.8740S 22.0480E 755 m	1940 to 2009	millimetres (mm)	SAWS
River flow	Paardendrift (J3H017)	33. 4045 22.0824E	1969 to 2009	cubic metres per second (m^3/s)	DWA

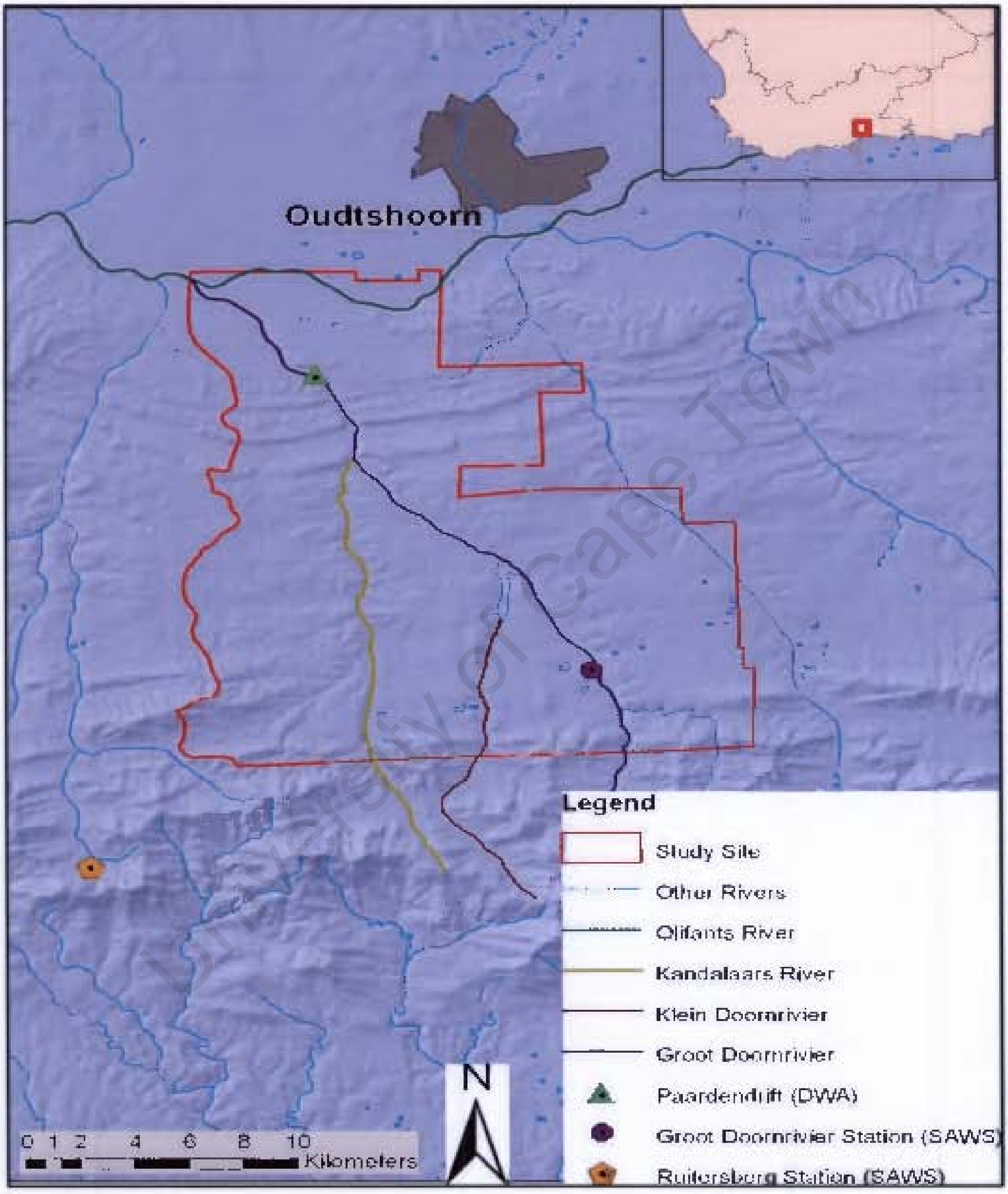

Figure 4.1: Locations of SAWS rainfall and DWA river flow stations within the Kandelaars catchment. Source: ENPAT (2002)

Newspaper articles on flooding from 1996 to 2008 in the Western Cape were obtained from sources, such as the Cape Times, and the Cape Argus.

Published and unpublished documents on flooding and loss reports used were acquired from sources, such as the Disaster Mitigation for Sustainable Livelihoods Programme, the African Centre for Disaster Studies (website: http://acds.co.za/index.php?page=publicatons), and Agri Klein Karoo.

The researcher also considered the use of Normalized Difference Vegetation Index (NDVI) to analyse land degradation in the Kandelaars catchment. However, after consulting the article by Tanser and Palmer (1999), the researcher opted otherwise. The authors state that spectrally based degradation assessment techniques do not function satisfactorily in semi-arid and arid environments. Additionally, they state that "vegetation indices that attempt to estimate net primary productivity cannot be used as reliable indicators of degradation status, because degradation does not necessarily result in a reduced level of plant growth" (Tanser & Palmer 1999:477).

4.4.2 Primary data collection: field visits

In order to collect observational data and meet with key informants in Oudtshoorn, the researcher conducted the first site visit from 3-5 June 2011. Unfortunately, as the avian influenza outbreak forced the closure of a number of farms in Oudtshoorn, these could not be visited.

However, two key informant interviews were possible: with a municipal engineer and with a farmer. The first interview was with a municipal engineer, who was familiar with the area's flood profile, especially recurrent damage to roads and bridges. The second interview took place with a farmer, whose farm had previously been flood affected. This allowed for information to be collected regarding the types of floods experienced, the extent of associated damage and any responses to alleviate loss.

The second field visit was carried out from 2-5 March 2012, owing to restricted access to farms during the previous trip. In this instance, farms were accessed, thereby enabling the researcher to visually assess the conditions of the ground cover. As this was done, photographs were taken to record the features, and compare the farm land to the surrounding natural ground cover. These data would verify the catchment conditions and land-cover types determined through the assessment of the aerial photographs in ArcGIS 9.2.

4.5 Data organization and consolidation

4.5.1 Overview of the process

The wide range of consulted data sources generated numerous records of uneven quality and reliability. Each data set (rainfall records, stream-flow data, time-series of aerial photographs) was therefore evaluated for its reliability and continuity; and additionally, it was organised for subsequent analysis. The processes for each of these procedures are explained below.

4.5.2 Organization and consolidation of aerial photographs and satellite images

In South Africa, National Geo-spatial Information (NGI), which is a component of the Department of Rural Development and Land Reform (DRDLR), commissions aerial photography for ongoing map revision, where significant land-cover changes are thought to have occurred, often over urban areas (NGI, 2011). Each set of resulting aerial photographs is accompanied by a flight plan with flight strips, over the specific terrain. These provide the line and sequence with which the aerial photographs were taken.

In this study, the researcher used the flight plans to select the appropriate photographs, which covered the Kandelaars catchment. This simplified the processes of merging photographs together; and it was done for each period.

There were several steps taken in preparing the spatial records of the Kandelaars catchment for subsequent land-cover analysis. Firstly, the researcher selected relevant aerial photographs from the time series collected. He then merged aerial photographs for each year by referring to the multiple flight plans, and the relevant flight strips across the catchment. This generated an integrated spatial image for each period. After this, it was possible to create catchment mosaics for each aerial photograph cluster.

The final step involved the georeferencing of the images from one year to the next, starting with 2008 and working back in time. The resulting image was used to georeference against; and this was regarded as the base map (see Figure 4.2).

Selection of aerial photographs

Table 4.4 lists the images that were used in the study. Two sets of images were discarded. The 1966 photographs were not used, because they did not cover a comprehensive portion of the catchment. The 2006 images were also abandoned, as the land-cover patterns closely resembled those of 2008.

Table 4.4: Display of the images used for the study and their respective characteristics

Year and Month	Image Type	Colour	Job Number	Scale	Pixel sizes within each image (metres)	Flight Strip(s)
1939 December	Aerial Photograph	Black and White	140	1:20 000	1.75	21,22,23,24,25, 26,27,28,29,30
1968 December	Aerial Photograph	Black and White	621	1:36 000	2.80	2,3,4,5,6,7,8
1974 June	Aerial Photograph	Black and White	736	1: 50 000	4.54	10,11,12
1985 May	Aerial Photograph	Black and White	889	1: 150 000	12.88	3,4
1991 October	Aerial Photograph	Black and White	959	1: 50 000	4.27	10,11,12
2001	Landsat Image	Panchromatic	N/A	30m resolution	28.50	N/A
2008	Spot 5 Image	Panchromatic	N/A	10m resolution	2.15	N/A

Compiling and aligning aerial photographs of specific periods with flight plans

For each period, the flight plan was used to select the photographs that were relevant for the Kandelaars catchment. This allowed for the images to be grouped together accordingly, for further consolidation in Adobe Photoshop CS3.

Generation of mosaics

The researcher used Adobe Photoshop CS3 to crop (remove the frame) and align each photograph. As each photograph was numbered sequentially with the flight strip, this allowed the images to be compiled systematically. After the images were aligned, they formed an image of the landscape in the form of a mosaic. These are presented in Figure 4.2.

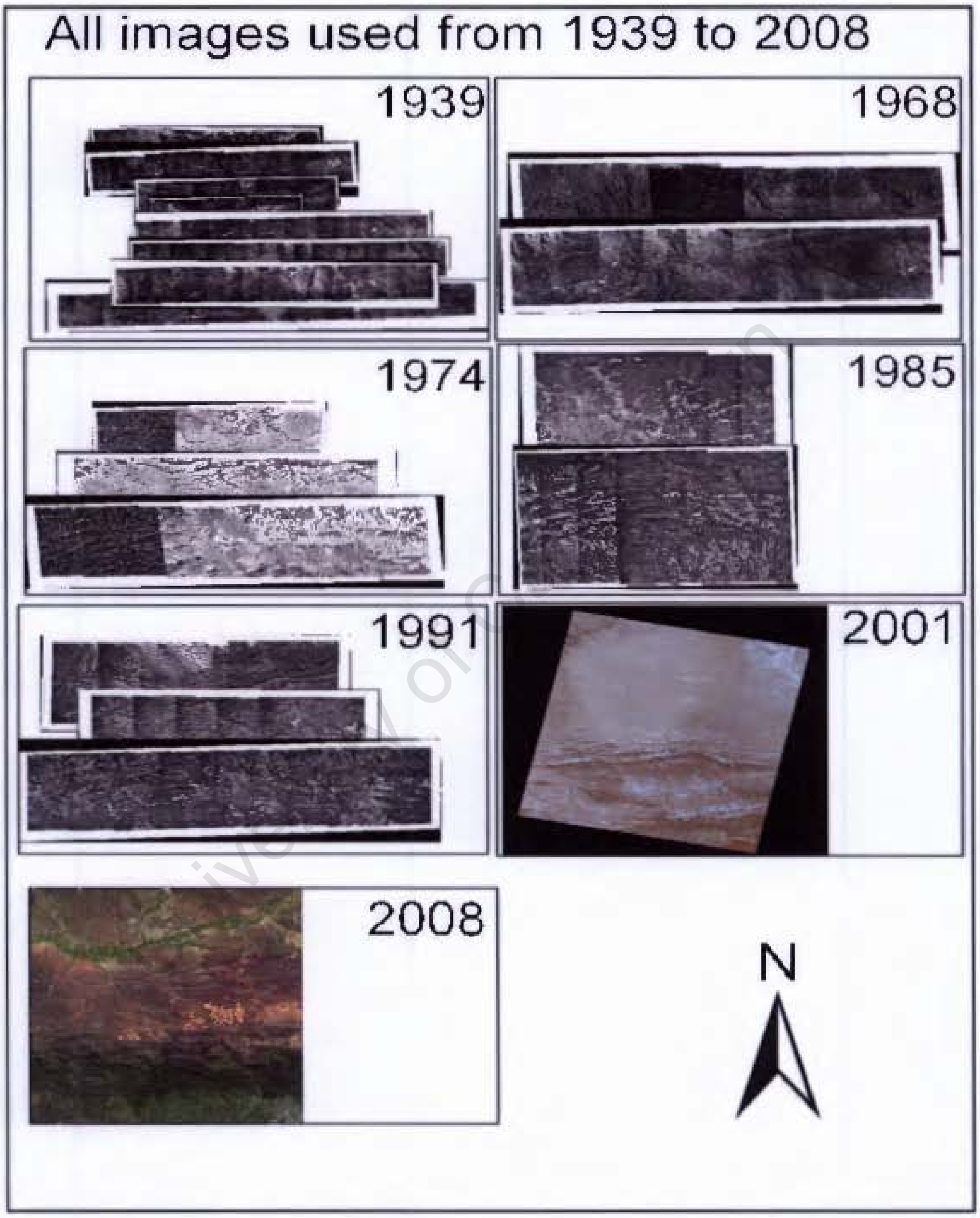

Figure 4.2: Complete set of the georeferenced images used in the study

Alignment of images through georeferencing

In order to place an image in its correct geographic location, all the spatial images were georeferenced to a base image by means of a map co-ordinate system (Li & Briggs, n.d.). This process of georeferencing involves the use of control points that exist in all images being matched – to allow the image to automatically adjust as the connections are made (Shoshani & Degani, 1992).

For the purposes of this study, five control points were identified and applied. These included buildings, and road intersections. Natural features, such as vegetation and rivers, were not used as control points. Rivers, for example, were noted to meander over time due to erosion; and they were further distorted by the angles at which the images were taken from the aircraft.

Image overlaying

Image overlaying involves aligning the seven sets of images in the time-series analysis, over each other, as is shown in Figure 4.3. This enabled a boundary common to all images, of an estimated 382 km^2, to be drawn around the area in the Kandelaars catchment. Hence, the study site determined, allowed for land-cover change analysis for part of, but, not for the entire catchment.

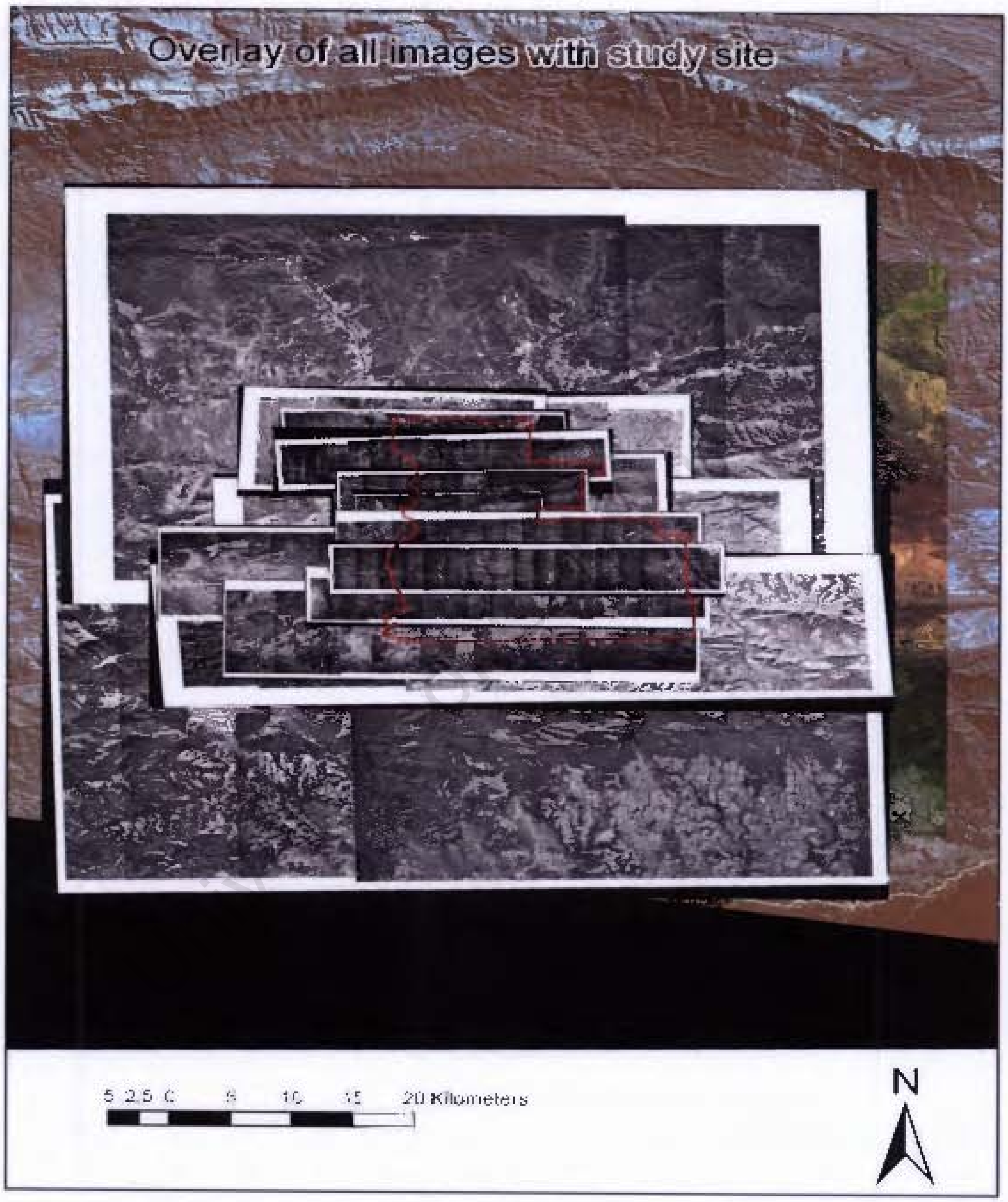

Figure 4.3: Overlay of all the images used in the study

4.5.3 Organisation and consolidation of rainfall and river-flow data

The rainfall and river-flow data were freely provided by the South African Weather Services (SAWS), and were available online through the Department of Water Affairs (DWA). The researcher used a Google Earth shapefile containing the locations of the weather stations across South Africa – in order to identify the weather stations in the Kandelaars catchment. The data for these specific sites were requested from SAWS.

River-flow data were obtained from the DWA website. By entering the catchment and river name into the data base, the researcher could download the necessary data.

Before analyzing the changes in extreme rainfall and flood occurrence, it was necessary to systematically organise the rainfall and river-flow records into two coherent time series of records. Both the rainfall and surface data were then carefully evaluated for their reliability, as this would influence the accuracy of the analysis (Kundzewicz & Robson, 2004).

Rainfall data

The first set of rainfall data, collected at Ruitersberg station, contained data from 1940 to 2008. However, the researcher noted significant gaps in the rainfall record from 1973 to 2008, and due to the unevenness of this part of the record, the data were only used from 1940 to 31 December 1972.

The second set of rainfall data, acquired from the Groot Doornrivier station, contained data from 1926 to 2008. Although this data set was also incomplete, the gaps were less significant. For instance, between 1982 and 2008, 14 values (0.14%) were missing out of 9,852; and between 1926 and 2008, 56 values (0.19%) had been omitted out of a total 30,257.

River-flow data

The Kandelaars River discharge record at Paardendrift extended from 1969 to 2008. Unfortunately, similar problems were encountered with the river-flow data as had been experienced with the rainfall records. Prior to 1982, the corresponding quality codes for many of the discharge values stated *missing data.* However, from 1982 to 2008, the records had corresponding quality codes, which stated *good continuous data* or *good edited data*. The researcher, therefore, chose to use the data from 1982 to 2008, because the use of the full record (i.e. including the values prior to 1982) would have limited the robustness of the analysis. A full description of the quality codes is available in Appendix 2.

4.5.4 Organisation and consolidation of the qualitative data

Information from the field research, flood episodes and newspaper articles was evaluated and arranged in specific themes, using Microsoft Office 2007. The themes selected were:

- Types of floods and causes;
- Damage associated with flooding;
- Government support to enable flood-loss recovery.

4.6 The data analysis

4.6.1 Overview

As this study set out to examine changing rainfall and land-cover conditions, in relation to flood occurrence in the Kandelaars catchment, the analysis phase sought to identify any changes in rainfall and river-flow extremes. It also aimed to trace changes in vegetation cover that could have exacerbated the surface runoff, due to reduced soil infiltration.

4.6.2 Determination of land-cover change

Overview

After the spatial boundaries of the study site were determined, classification and calculation of the land-cover types was carried out for each of the images. The results allowed for a comparison of the quantity of each land-cover type over time. Thompson (1996:37) proposed a standard land-cover classification scheme for remote sensing applications in South Africa. The researcher drew on land-cover classes from the classifications that were known both to apply to the area of study, namely the Little Karoo biome, and to be associated with flooding, should they be altered.

Table 4.5: Land-cover types identified in the Kandelaars catchment. Source: adapted from Thompson, 1996

LAND-COVER TYPE	DESCRIPTION
Cultivated Land	Areas currently ploughed and awaiting harvesting or being prepared to accommodate crop production in the future
Riparian Vegetation	Vegetation of a very dark and thick texture, lying adjacent to the river and following its course
Water Bodies	Areas of trapped water inclusive of dams and lakes which can be natural or man-made
Low shrubland and Fynbos	Low woody self supporting plants mixed in with small leaved ever-green plants
Urban and built-up area	Man-made developmental features. They are unnatural to the area and often concentrated, being commercial or residential.

The digitization process created separate shape files for each of the years. This allowed polygons to be drawn over the aerial photographs and satellite images without affecting the original images, and to form new raster data types (Environmental Systems Research Institute, 2011).

The visibility of the land-cover types in each image was dependent on the size of the pixels (Table 4.4). The larger the pixel size, the more difficult it was to determine a particular feature on the ground. Hence, as pointed out by Kadmon and Harari-Kremer (1999), differentiating between vegetation types, particularly of very small sizes, can be very difficult and is necessarily subjective. In addition, the process may also be time consuming.

These reasons further substantiated the researcher's selection of the coarse land-cover classes for this study.

As the drawing occurred, each feature was labelled, according to the classification scheme, as described in Table 4.5. The boundaries ensured that the drawing was done within the area common to all images. For calculation purposes, this also guaranteed that the total area would be the same in all the images. On completing the digitization, the researcher discarded the additional drawing outside the study site boundary. The process was concluded by using ArcGIS 9.2 to count the number of cells accommodated by each of the land-cover types – to thereby provide the total area of each class.

The output parameter chosen was kilometres squared (km^2). For each land-cover mosaic and satellite image, specific land-cover types were quantified and exported for use in MS Excel, where calculations could be made, and the results could be interpreted.

Shapefiles of the farm boundaries and registered ostrich farms were then placed over the digitized 2008 image. This illustrated other areas in the catchment that carry out forms of agricultural activity other than ploughed agriculture. Ploughed agriculture is simple to identify on aerial photographs – owing to the distinct rectangular lines for fields; but this neglects the possibility of any agricultural activity elsewhere, such as ostrich and sheep rearing, which both use fencing; and these boundaries are not easily detectable.

4.6.3 Determination of changes in rainfall extremes and frequency of heavy rainfall

<u>**Overview**</u>

As part of the statistical methods, the researcher used Exploratory Data Analysis (EDA). This is understood to be an advanced visual examination of the data (Kundewicz & Robson, 2004). It involves using graphs to explore, understand and present the data. When conducted well, it is a powerful tool capable of eliminating the need for a formal statistical analysis (Kundewicz & Robson, 2004).

In addition, the researcher also used various probability distribution functions for the flood-frequency analysis. These are discussed in Chapter 2 section 7. These may be applied to a set of historical data for a given site (Alexander, 2002: 97). The rationale for these methods is based on their documented effectiveness for identifying extreme flood events and their fluctuations over time (Alexander, 2002).

Using Microsoft Excel 2007, the Weibull formula described by Pengram and Parak (2004:278) was adopted to find the return periods for specific peaks in the data. To improve the effectiveness of the formula, SANRAL (2007) was consulted for the relevant plotting positions needed to determine the return periods for the extreme events.

SANRAL (2007) states that for locations with regular and high intensity rainfall, such as the South and South-Western Cape, the General Extreme Value (GEV) functions yield better results. The Gringorten (1963) and Greenwood (1979) plotting positions met this criterion, of which the researcher opted to use the former. Other plotting positions – without GEV functions – are outlined in Chapter 2 section 7; and a number of these can be viewed in Appendix 1.

$$T = \frac{n+a}{m-b}$$

Where:

T = the return period in years

n = length of record in years

m = rank number, in descending order, of the total ranked-annual peak floods

a = constant (0.12 for Gringorten plotting position)

b = constant (0.44 for Gringorten plotting position)

The Annual Maximum Series and its application

The Annual Maximum Series indicates the change in the frequency and intensity of extreme rainfall and river-flow events, by comparing the highest value for each year within the series (also referred to as the return periods) (Pengram & Parak, 2004; Van Bladaren, 2007). This is calculated as a probability, indicating the likelihood of the event repeating itself, for example a 20-year flood has a 5% chance of occurring in any given year (Alexander, 2000).

<u>The Partial Duration Series and its application</u>

The Partial Duration Series (PDS), also regarded as Peaks over Threshold (PoT) (Van Bladaren, 2007; Mkhandi *et al.*, n.d.), is generally used for short data sets of about five to ten years (Alexander, 2000). However, for a large dataset, it provides an indication of the shifting trends in extreme rainfall and river-flow events over time, and whether these are concentrated at particular periods. This is because it compares the highest values within a selected series; and there is no limit to the number of peak values that can be incorporated from separate events in any given year.

4.7 Summary

This chapter has outlined the quantitative and qualitative methods used for the study. These comprised secondary and primary data. The chapter has further detailed the collection, consolidation and analysis of the data, and also indicated the effectiveness and constraints of the data. This study has combined both the desk-top and the field research which took place in June 2011, and March 2012.

Chapter Five: Analysis and Findings

5.1 Introduction

This chapter presents the study results, the findings and the analysis. It begins by describing rainfall patterns and trends in the Kandelaars catchment. It specifically shows how extreme rainfall patterns have varied over the past 80 years, in relation to frequency and seasonality. This is followed by the analysis of recent river-flow records of the Kandelaars catchment, describing the frequency and magnitude of these extreme floods. It continues by examining the relationship between extreme rainfall and floods recorded between 1982 and 2008. This leads to a description of land-cover changes from 1939-2008; and it concludes by displaying the results of the field visit carried out in March 2012.

5.2 Rainfall trends in the Kandelaars catchment

5.2.1 Overview

This study has sought to examine rainfall trends within the Kandelaars catchment, to determine whether there has been an increasing occurrence of heavy rainfall events. The results below present the observed annual rainfall from two weather stations. This is followed by a summary of the average annual rainfall records, clustered by decade – from 1926 to 2008, for the Groot Doornrivier rainfall station.

5.2.2 Annual rainfall: Kandelaars catchment 1926-2008

Figures 5.1 and 5.2 represent present the recorded annual rainfall for the Ruitersberg and Groot Doornrivier rainfall stations. These illustrate the effects of altitude on heavy rainfall, with average annual rainfall of 766mm recorded from 1941 to 1972 for the Ruitersberg station located in the mountainous upper catchment. However, as explained in section 4.5.3, the data from this station were not used, due to the incompleteness of the record.

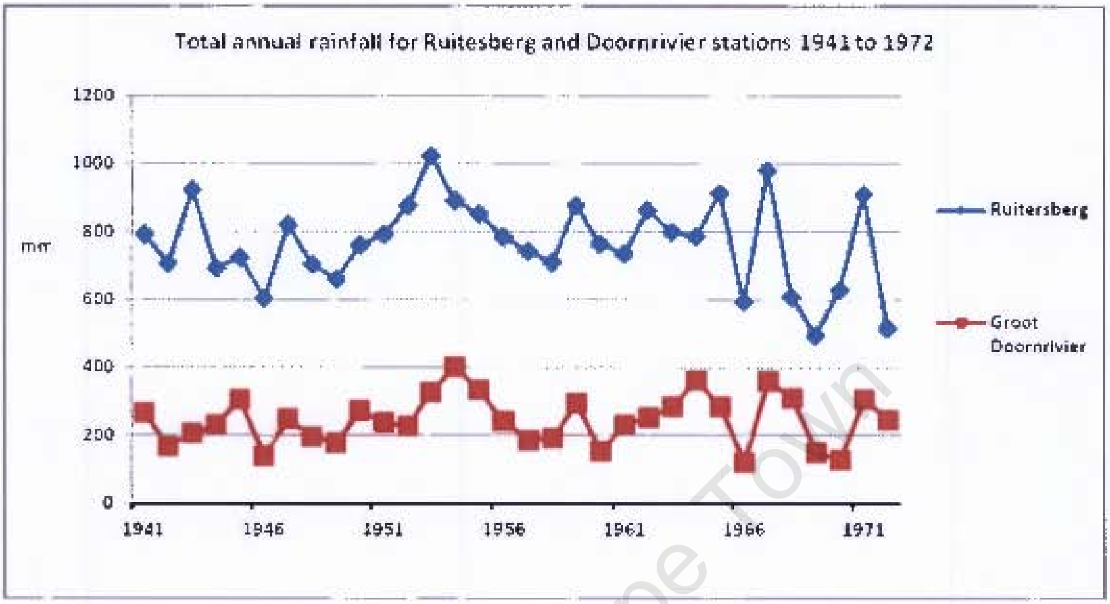

Figure 5.1: Total annual rainfall for Ruitersberg and Groot Doornrivier stations from 1941 to 1972

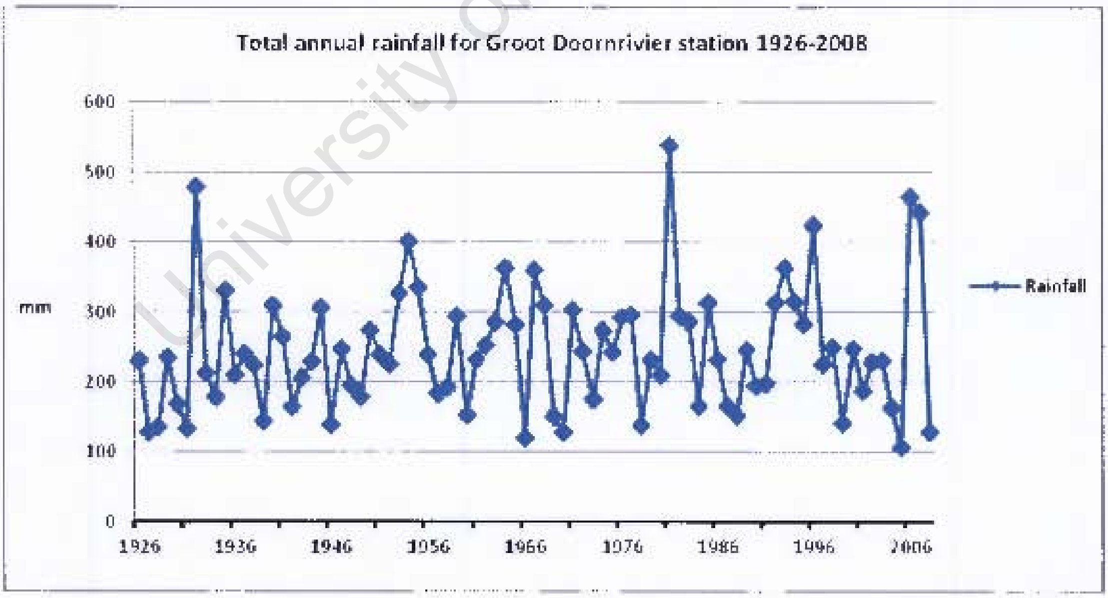

Figure 5.2: Total annual rainfall for Groot Doornrivier station from 1926 to 2008

Figure 5.2 represents the annual rainfall from 1926-2008, recorded at the Groot Doornrivier station located in the lower catchment (refer to Figure 4.1, methods). A total of 2,490 rain days were recorded for the Groot Doornrivier station over a period of 82 years, with an average annual rainfall of 245mm.

5.2.3 The frequency of rain days and rainfall volume

On average, there were 30 rainy days annually from 1926-2008. However, the findings indicate a declining trend in annual rainy days in the latter years of the record. This is evidenced in Table 5.1 and Figure 5.3 that represent annual rainfall data and the frequency of rainy days for each decade.

Table 5.1: Decadal average annual rainfall and rainy days: Groote Doornrivier rainfall station, Kandelaars catchment 1929-2008

Period	Decadal average annual rainfall (mm)	Decadal average annual rain days per year	Decadal average rainfall per rain day
1929-1938	241.59	32	7.62
1939-1948	220.95	29	7.65
1949-1958	259.68	29	8.92
1959-1968	265.41	33	7.99
1969-1978	224.43	27	8.34
1979-1988	276.58	34	8.06
1989-1998	280.94	34	8.21
1999-2008	234.51	24	9.81

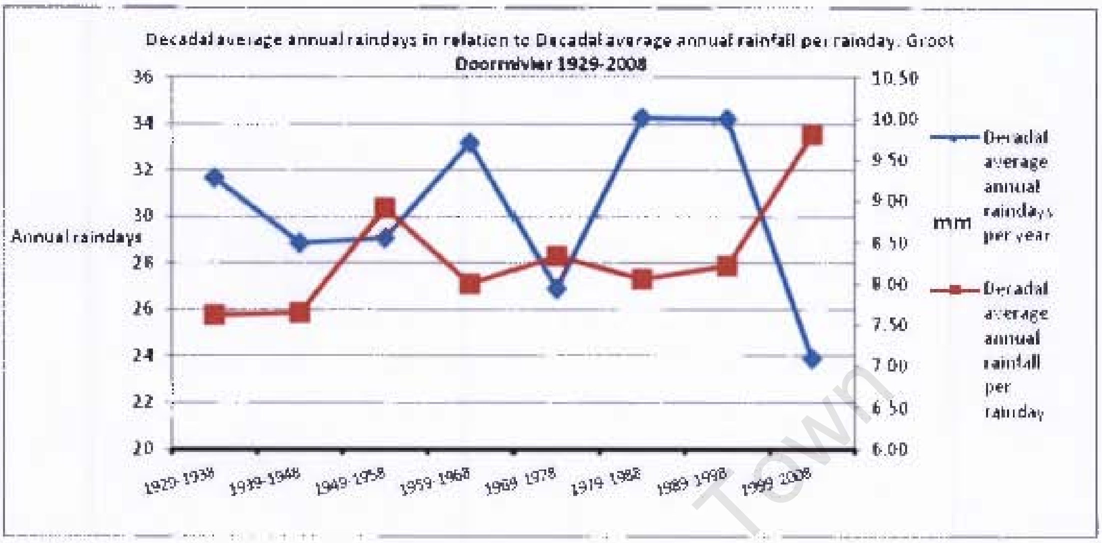

Figure 5.3: Decadal average annual rainfall in relation to the average annual number of rainy days: Groot Doornrivier rainfall stations, Kandelaars catchment, 1929-2008

Significantly, from 1991 onwards, both Figure 5.3 and Table 5.1 show a declining frequency of rainy days, with only nine rain days reported in 2008. The data suggest increasing rainfall variability in the past decade, with heavy rainfalls noted in 2006 and 2007, respectively, despite the 24 rainy days noted in each year.

5.3 Determination of extreme rainfalls

5.3.1 Occurrence of extreme rainfall events 1926-2008

Due to the focus of the study on extreme rainfall events, the researcher examined the frequency of rainfall events of above 50mm during the 82-year study period. These results, reflected in Figure 5.4, show that 33 rainfall events of 50mm or greater occurred from 1926-2008, along with 14 rainfall events of at least 70mm. Significantly, 8 rainfall events of 70mm or more were recorded from 1993 to 2008, compared with 6 events distributed over 66 years from 1926 to 1992.

This indicates a shorter recurrence interval for heavier rainfalls in the more recent rainfall record.

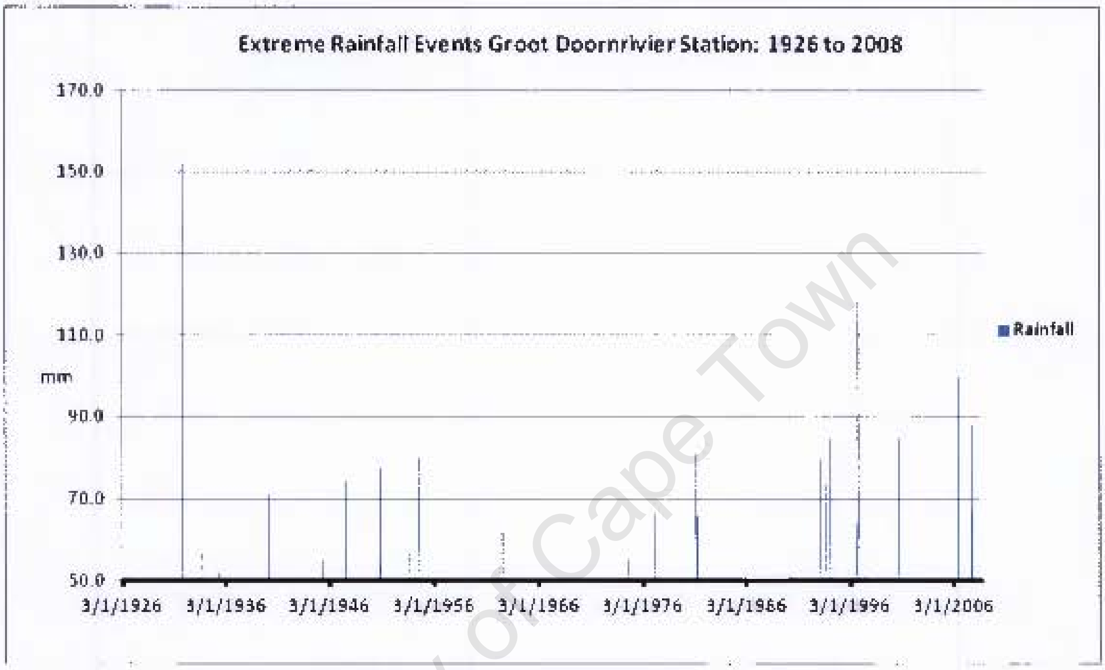

Figure 5.4: Temporal distribution of rainfall events >50mm at Groot Doornrivier station from 1926 to 2008

5.3.2 Determination of return intervals for rainfall extremes

This trend in favour of increasing rainfall intensity is further evidenced by findings derived from applying the Annual Maximum Series approach to rainfall-data records from 1926-1966 and 1967-2008 at the Groot Doornrivier Station. Tables 5.2 and 5.3, respectively, apply the Gringorten 1963 plotting positions (SANRAL, 2007) to show a marked reduction in the return periods for rainfall events of 80mm or higher.

Table 5.2 presents the rainfall data from 1926 to 1966. It shows the occurrence of an extreme rainfall event of 151.9mm in 1932. However, over this first 40-year reporting period, only one other noteworthy annual rainfall event of 80mm (27 August 1954) was recorded. The AMS findings determined this event to have a return interval of 25.75 years.

This contrasts markedly with the AMS findings for the second reporting period from 1967-2008, reflected in Table 5.3. The results indicate seven rainfall events of at least 80mm over a 27-year period, with 80mm rainfall events now determined to have a 6-7 year recurrence interval. This is a significantly shorter recurrence interval than in the pre-1967 series, in which a comparable rainfall event was determined to have a 26-year return period.

In addition to the shortening of return periods for heavy rainfall events, Tables 5.2 and 5.3 also show an increasing frequency of more intense rainfall events in the recent rainfall record. The findings also suggest some seasonal drift in the occurrence of heavy rainfall events. This is indicated by the occurrence of three heavy rainfall events in August, for the period 1926-1966, compared with four events in November for 1967-2008.

Table 5.2: Heavy rainfall return periods: Groot Doornrivier station 1926 to 1966 (Full table in Appendix 3)

Groot Doornrivier station rainfall return periods from 1926 to 1966				
Rank	Date (m/d/y)	Rainfall (mm)	Annual Probability (1/y)	Return Periods (y)
1	1/1/1932	151.9	0.01	68.67
2	8/27/1954	80.0	0.04	25.75
3	1/12/1951	77.5	0.06	15.85
4	9/16/1947	74.4	0.09	11.44
5	4/6/1940	71.1	0.11	8.96
6	8/20/1962	62.0	0.14	7.36
7	8/29/1933	57.7	0.16	6.24
8	10/20/1953	57.0	0.18	5.42
9	5/23/1945	54.9	0.21	4.79
10	11/11/1950	54.4	0.23	4.29

Table 5.3: Heavy rainfall return periods: Groot Doornrivier station 1967 to 2008 (Full table in Appendix 4)

Groot Doornrivier station rainfall return periods from 1967 to 2008				
Rank	Date (m/d/y)	Rainfall (mm)	Annual Probability (1/y)	Return Periods (y)
1	11/20/1996	118.0	0.01	68.67
2	8/2/2006	100.0	0.04	25.75
3	11/22/2007	88.0	0.06	15.85
4	11/6/2000	85.0	0.09	11.44
5	3/6/1994	84.4	0.11	8.96
6	4/26/1981	81.0	0.14	7.36
7	4/11/1993	79.8	0.16	6.24
8	5/8/1977	66.5	0.18	5.42
9	8/22/1974	55.0	0.21	4.79
10	11/28/1995	50.5	0.23	4.29

5.4 River flows recorded at Paardendrift station (J3H017), 1982-2008

5.4.1 River flows 1982-2008

The study's specific focus on changes in flood frequency over time within the Kandelaars catchment also required the researcher to examine river flows. These data derived from the Paardendrift station, as reflected in Figures 5.5 and 5.6, indicate an increasing frequency of heavy flows in recent years. Five, of seven flood occurrences, between 1982 and 2008, of 35m^3/s or more, were recorded during the period 2000 to 2008.

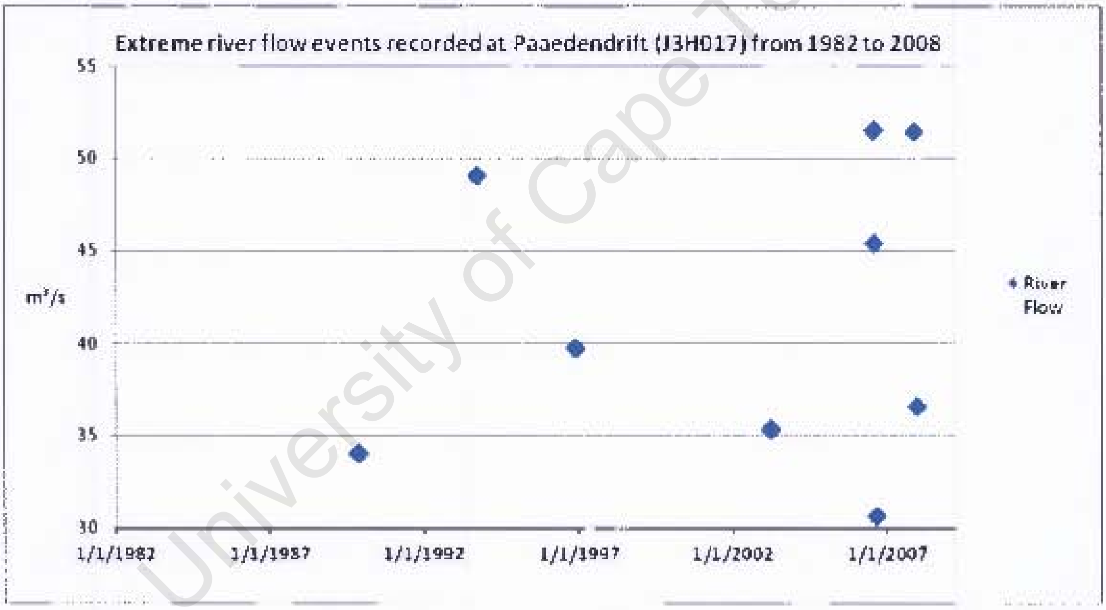

Figure 5.5: Extreme discharge values recorded at Paardendrift (J3H017) from 1982-2008

Figure 5.6 also illustrates a very steep increase in the total annual river-flow levels in the catchment area in 2006 and 2007. These discharge levels are higher than any previous records within the 27-year timeframe.

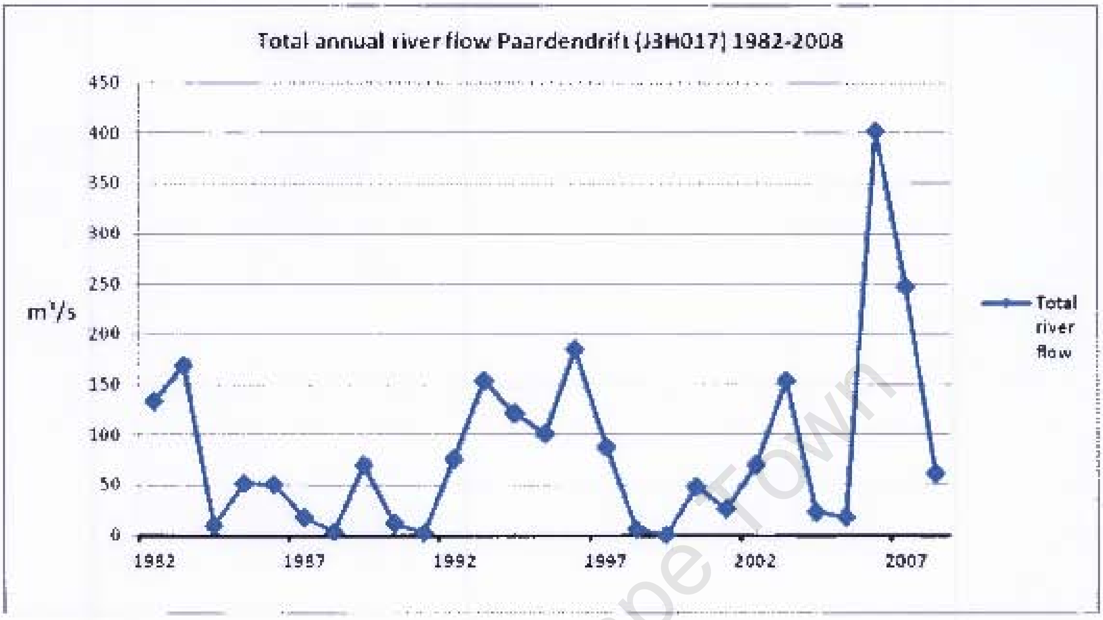

Figure 5.6: Total annual river flow recorded at Paardendrift (J3H017) from 1982-2008

5.4.2 Determination of extreme floods and return periods

Table 5.2 presents the results of applying the Annual Maximum Series approach to river-flow levels recorded at Paardendrift from 1982-2008. This indicates that four, of the 10 most intense annual floods over the record, occurred from 2000-2008. Annual flooding in 2006 and 2007 represented particularly significant magnitudes, exceeding $50m^3/s$, in both instances.

Table 5.4: Large river flow AMS return periods: Paardendrift station using: 1982-2008 (full table available in Appendix 5)

Paardendrift station (J3H017) river flow return periods from1982 to 2008				
Rank	Date(m/d/y)	River flow	Annual Probability (1/y)	Return Periods (y)
1	8/2/2006	51.51	0.02	45.33
2	11/23/2007	51.50	0.06	17.00
3	9/24/1993	49.09	0.10	10.46
4	11/22/1996	39.72	0.13	7.56
5	3/25/2003	35.33	0.17	5.91
6	11/16/1989	34.03	0.21	4.86
7	10/16/1992	23.47	0.24	4.12
8	7/27/1983	20.29	0.28	3.58
9	11/13/2000	16.90	0.32	3.16
10	3/7/1994	14.91	0.35	2.83

As with the more extreme rainfall reported in section 5.3, river-flow findings suggest seasonal drift to the later months of the year. This is indicated by the occurrence of five of the most significant floods in October (1992) and November (1989, 2000, 1996 and 2007).

5.5 Relationships between extreme rainfall and river flow

5.5.1 Determination of high intensity floods 1982-2008

A central question for this research was whether more extreme floods within the Kandelaars catchment were associated with high magnitude rainfall events. Figure 5.7 presents the findings related to heavy rainfall and flooding in the Kandelaars from 1982-2008. Although all floods are associated with rainfall events, the magnitudes vary. For instance, Figure 5.7 shows a heavy rainfall event (118mm) in 1996 that was associated with significant river flow of 39.7m^3/s.

However, three years earlier, a recorded river flow of 49.08m^3/s was associated with rainfall of 73.5mm.

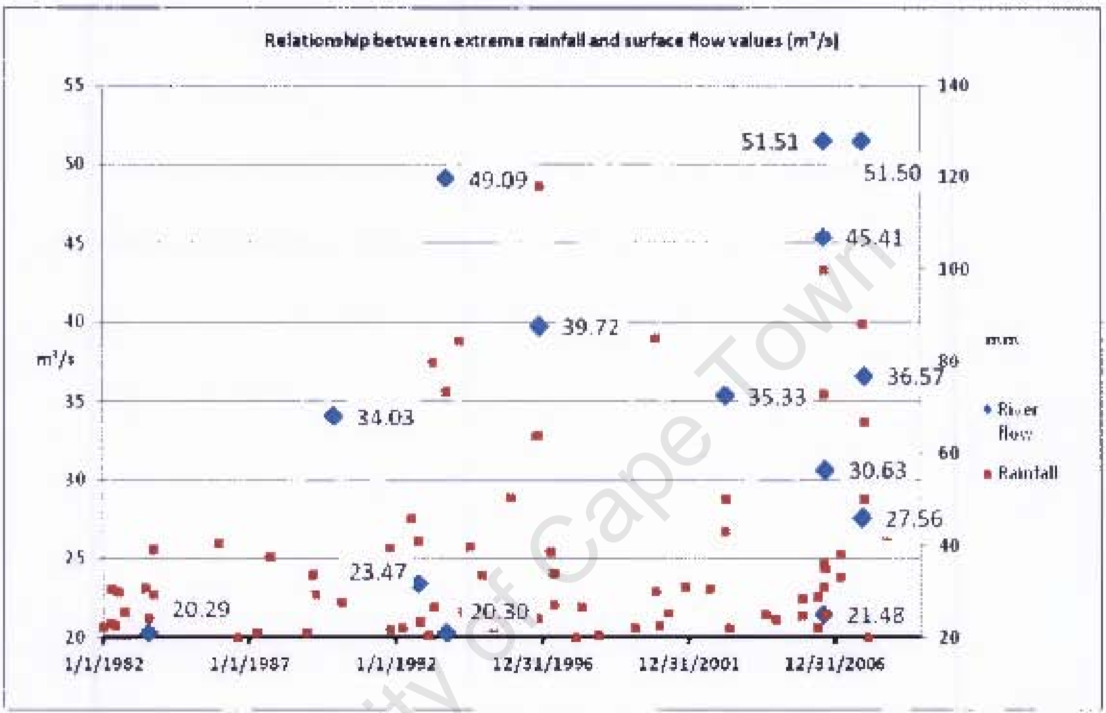

Figure 5.7: Relationship between rainfall events and river flows: Groot Doornrivier rainfall station and Paardendrift (J3H017)

5.5.2 Determination of extreme floods 1982-2008

Table 5.5 presents the findings generated by the application of the Partial Duration Series (PDS) approach to river-flow data from Paardendrift from 1982-2008, along with the associated rainfall.

It shows that in 2006 and 2007 there were three floods in both years, with two of the floods from each year ranking in the top 10 discharges recorded. Prior to this, only 1983 recorded three floods in one year, but with lower discharge levels. Although other years recorded two floods (1982, 1983, 1986, 1993, 1994, 1995 and 1996), the discharge levels were not always significant.

These data indicate that most flooding within the Kandelaars catchment takes place either early or late in the year. The results listed in Table 5.5 show that 66% (19 out of 29) of the floods occur between August and February. As many as 50% (5 out of 10) of the floods recording the highest river flows occurred in October and November. Table 5.5 also shows that most floods reflect a cumulative high total rainfall over five days. Large discharges, such as those associated with 16 November 1989 (rank 7), with a low rainfall total suggesting a storm characterised by either much higher rainfall concentrated further up in the mountains, or rainfall widely spread throughout the catchment area.

Table 5.5: Comparison of 29 highest daily river flow return period rankings to associated rainfall using the partial duration series (corresponding colours indicate floods from the same year)

29 largest river flow peaks (Partial Duration Series)									
Rank	Date (y/m/d)	Discharge (m^3/s)	Rainfall (mm)	Rainfall (mm) days recorded prior to the peak river flow					Total (mm)
				1	2	3	4	5	
1	2006/08/02	51.51	100.0	73.0	36.0	0.0	0.0	0.0	109.0
2	2007/11/23	51.50	0.0	88.0	24.0	0.0	0.0	0.0	112.0
3	1993/09/24	49.09	0.0	2.0	73.5	5.5	10.0	0.0	91.0
4	1996/11/22	39.72	0.0	0.0	118.0	14.7	0.0	0.0	132.7
5	2007/12/26	36.57	67.0	50.0	2.0	13.0	0.0	0.0	65.0
6	2003/03/25	35.33	0.0	0.0	50.0	43.0	7.0	0.0	100.0
7	1989/11/16	34.03	0.0	0.0	18.7	6.5	0.0	0.0	25.2
8	2006/08/25	30.63	0.0	35.0	25.0	0.0	0.0	0.0	60.0
9	1992/10/16	23.47	0.0	10.3	41.0	0.0	0.0	0.0	51.3
10	1983/07/27	20.29	1.0	13.5	24.3	15.0	0.0	0.0	52.8
11	1983/10/03	17.99	0.0	29.5	0.0	0.0	0.0	0.0	29.5
12	1996/10/23	17.91	2.0	1.0	64.0	14.0	1.7	24.2	104.9
13	2000/11/13	16.90	0.0	0.0	30.0	0.0	0.0	0.0	30.0
14	2006/05/21	14.93	5.0	22.0	29.0	16.0	4.0	0.0	71.0
15	1994/03/07	14.91	0.0	84.4	11.4	0.0	0.0	0.0	95.8
16	1993/04/13	14.77	0.0	0.0	79.8	19.3	0.0	0.0	99.1
17	1982/07/07	12.61	0.0	30.0	9.5	0.0	0.0	0.0	39.5
18	1982/04/29	11.95	13.6	30.5	1.5	6.0	1.6	0.0	39.6
19	1995/11/30	11.50	0.0	6.0	50.5	0.0	0.0	0.0	56.5
20	2002/09/11	10.94	0.0	0.0	6.5	30.5	0.0	0.0	37.0
21	1994/07/25	8.59	3.0	0.0	40.0	0.0	0.0	0.0	40.0
22	2007/03/06	8.35	0.0	0.0	33.0	38.0	0.0	0.0	71.0
23	1983/09/24	7.39	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	1985/12/21	7.18	0.0	0.0	40.5	0.0	0.0	0.0	40.5
25	1986/[illegible]	7.14	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	2003/05/11	7.00	0.0	0.0	22.0	0.0	0.0	0.0	22.0
27	1995/12/01	6.91	0.0	0.0	0.0	50.5	0.0	0.0	50.5
28	1986/08/31	6.69	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	1985/10/30	5.98	14.0	0.0	0.0	0.0	0.0	0.0	0.0

5.6 Land-cover change in the Kandelaars catchment

5.6.1 Overview

This research has also sought to examine whether more intense damaging flood occurrence in the Kandelaars catchment was influenced by hardening catchment conditions that increased surface runoff. This was explored through a time-series analysis of land-cover changes in the catchment area from 1939-2008.

Figure 5.8 represents the changes in land-cover over this period. It indicates an expansion in cultivated land within the catchment – much of which took place in the upper reaches of the catchment (the lower portion of the images), along the slopes, and adjacent to the river channel during the 1970s. Little visible change seems to have occurred in the lower and middle parts of the catchments. However, it is clear that significant agricultural expansion occurred in the upper parts of the catchment, adjacent to the Klein and Groot Doornriviers (see Figure 5.1 for river positions).

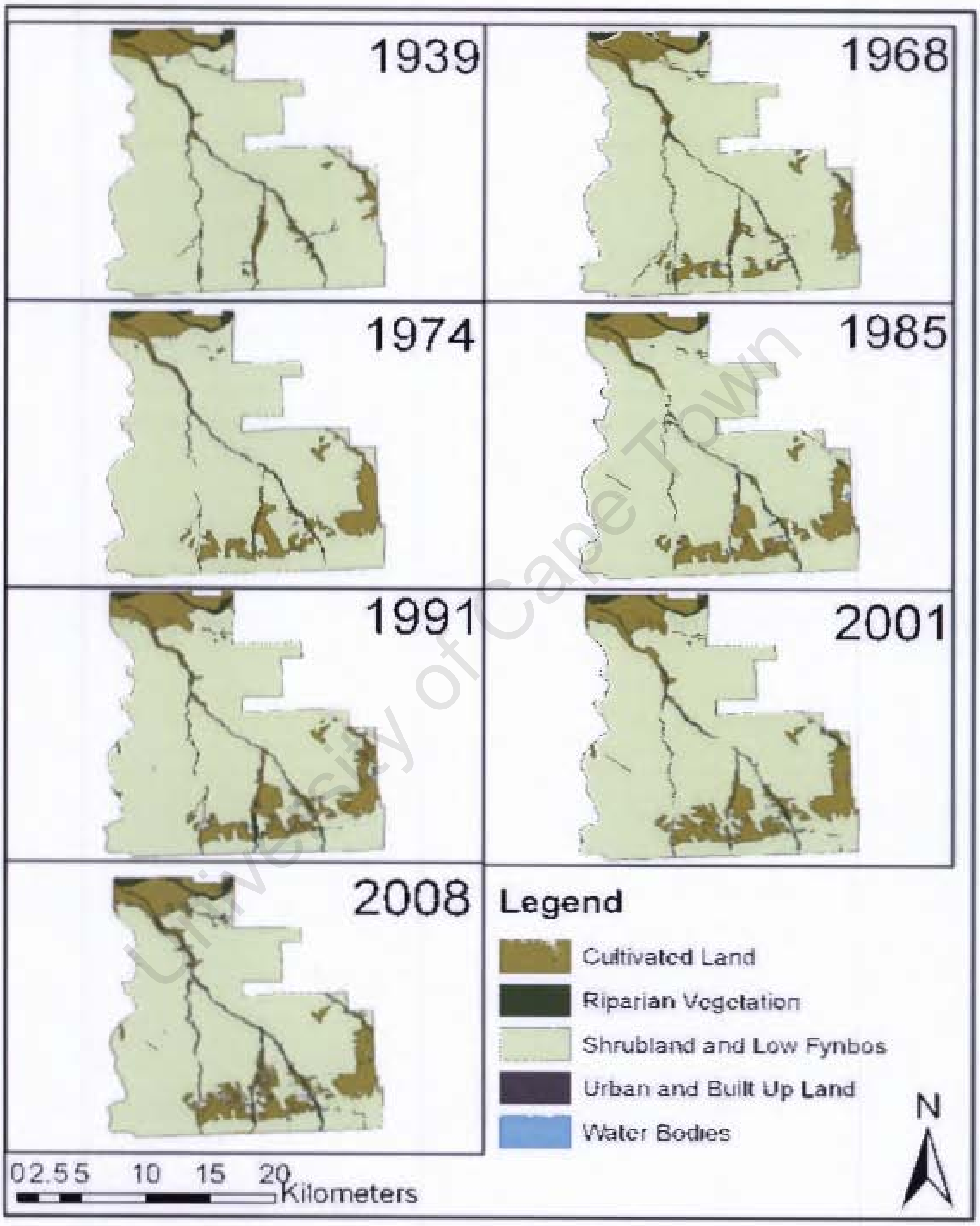

Figure 5.8: Time series representation of land-cover types. Kandelaars catchment: 1939-2008

5.6.2 Changes in specific land-cover types

Table 5.6 summarizes changes identified in the land-cover analysis from 1939-2008. It indicates the largest land-cover change was in that of cultivated land, most of which took place between the 1960s and 1970s: of 16.88%. Over 69 years, cultivated land increased by 129%, while the dominant land-cover type, shrubland and low fynbos, decreased by 10.1%. The large agricultural expansion correlates with the increasing built-up spaces, and the bodies of water in the area.

The decrease in the bodies of water in some stages, such as those of 1974, 1985 and 1991, in comparison with that in 1968, suggests that these periods may have been drier. This is further reflected in the decline in riparian vegetation during the same periods. The growth of riparian vegetation from 1991 onwards could also suggest a possible increase in the alien vegetation or cultivation encroaching onto the riparian zone.

Table 5.6: Spatial extent of different land-cover types: Kandelaars catchment 1939-2008

Land-cover Type	Areal extent for the years studied (km^2)							
	1939	**1968**	**1974**	**1985**	**1991**	**2001**	**2008**	**% change of each land-cover type 1939-2008**
Cultivated Land	21.79	34.77	40.64	42.04	45.27	50.51	49.90	128.99
Riparian Vegetation	7.73	7.97	6.60	6.46	7.05	7.40	8.98	16.22
Shrubland and Low Fynbos	298.50	285.08	280.71	279.43	275.32	269.63	268.37	-10.09
Urban and Built Up Land	0.06	0.02	0.12	0.16	0.29	0.19	0.43	680.97
Water Bodies	0.18	0.42	0.18	0.16	0.32	0.52	0.57	218.35

5.6.3 Focus on agricultural land-use- specifically ostrich farming

A central theme in this study was the determination of whether the expansion of ostrich farming had altered the catchment conditions, so that these increased the surface runoff during rainfall events. Unfortunately, the land-cover changes represented by the aerial photographs and satellite images via the subsequent digitization in ArcGIS 9.2 were insufficiently sensitive to show the changes in natural vegetation attributed to trampling or loss of plant cover due to pecking behaviour. Both these consequences of ostrich farming have the potential to reduce surface infiltration of the soil.

The incorporation of the ostrich-farming shapefile (see Figure 5.9), however, does represent the location of registered ostrich farms within the catchment. It includes significant ostrich farming activity in the upper reaches of the catchment. It is also worth noting that the other farm boundaries spread across the catchment area indicate where additional forms of livestock rearing may have taken place, which could vary between sheep, goat, cattle, and ostrich farming that was not registered with the SAOBC.

This, combined with the evidence of extensive cultivation between the Groot Doornrivier and the Klein Doornrivier, suggests significant upper catchment development. Such development, accompanied by changing catchment conditions (such as compacting and reduced surface infiltration) may also have contributed to increased overland flows, and subsequently larger river discharges.

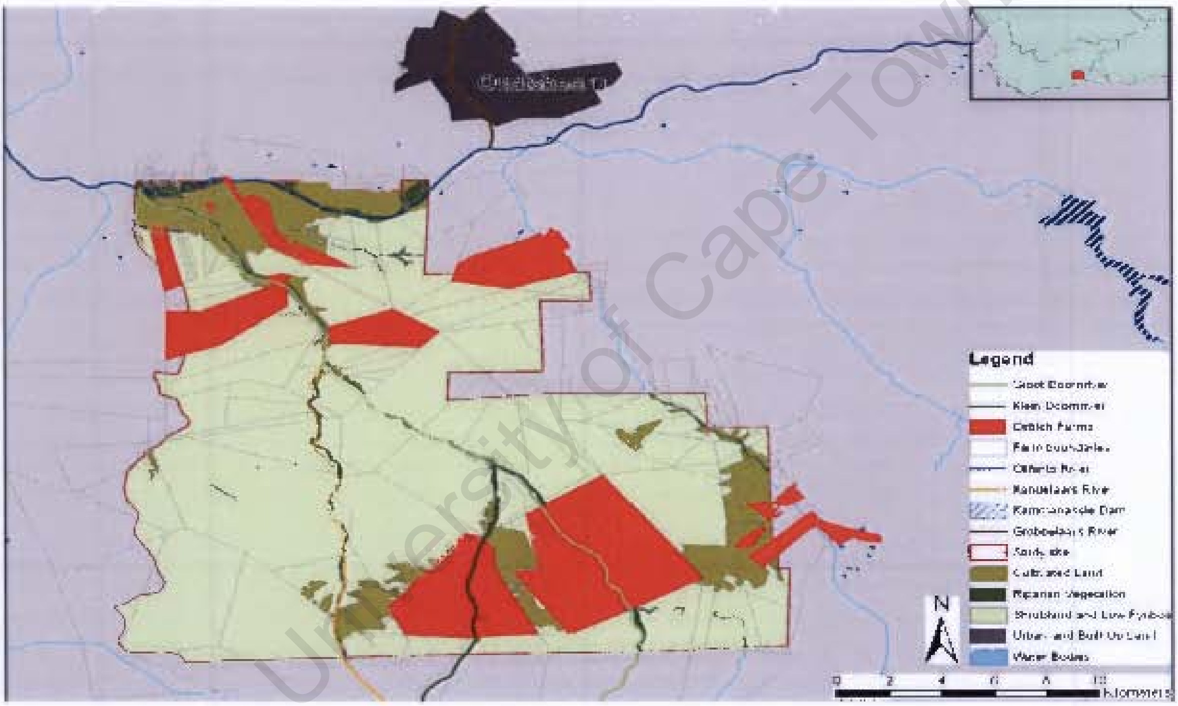

Figure 5.9: 2008 image with the digitized land-cover types, with overlapping farm boundaries located in the study site. Sources: SAOBC [2007] and ENPAT (2002)

Although the land-cover assessment using Arc9.2 was insufficiently sensitive to determine the full extent of the degradation in the Kandelaars catchment, the March 2012 field visit allowed the researcher to verify the conditions of farms – where ostriches are kept in open areas, and in more confined enclosures. These are illustrated in Figures 5.10 and 5.11. In both scenarios the vegetation was sparser than the surrounding natural ground cover. However, in the case of the latter, the rearing of ostriches had evidently led to barely any vegetation being left on the ground.

The surfaces comprise mostly sand, stone – and in more extreme cases – even exposed rock.

Additional land degradation was evident on other livestock rearing farms, which catered for sheep, goats and cows (see Appendix 6). Also similar to the cases of ostrich rearing, other livestock kept in confined spaces could well have caused more degradation.

A constraint to the field visit is that it was not feasible for this scale of study, for the researcher to visit every farm within the catchment area. This could have provided more information on the ostrich densities on the various farms, and the conditions under which the birds are kept.

Source: Field visit to Oudtshoorn, March 2012.

Figure 5.10: Ostrich rearing in open areas

Source: Field visit to Oudtshoorn, March 2012.

Figure 5.11: Ostrich rearing in confined spaces

5.7 Summary

This chapter has presented the findings of the study. These were illustrated in the form of graphs, tables and figures. These findings showed changes in seasonality, and increasing frequency and intensity of both rainfall and river flow. They further revealed changes in the characteristics of the land-cover in the catchment area. Much of the change appears to be related to agricultural expansion, primarily in the upper part of the catchment. The field visit ground-truthed the features assessed in the spatial analysis, and presented evidence of the extent to which ostrich farming is affecting the ground cover in Oudtshoorn.

Chapter Six: Discussion and Conclusion

6.1 Introduction

This concluding chapter discusses the findings in relation to the prevailing literature on flash flooding, particularly those related to the two risk drivers that are the focus of this study, as indicated in the conceptual framework: rainfall and land-cover.

The chapter begins by discussing the findings related to trend, seasonality and intensity of rainfall over the study period, and how these findings relate to high magnitude river flows. The chapter continues by examining changes in land-cover associated with the identified implications for increased flood occurrences. It then proposes additional research opportunities that have emerged during the course of the study; and it concludes by briefly revisiting the research objectives and the results.

6.2 Rainfall findings and the implications on flooding

To examine the changes in the frequency and intensity of rainfall events in the Kandelaars catchment, the researcher applied the EDA and AMS statistical approaches to the rainfall data.

The study results reflected in Tables 5.2 and 5.3 indicate that extreme rainfall events are becoming more frequent and intense; and that they are shifting in seasonality. Between 1926 and 1966 (Table 5.2), in the early years of the study, only two rainfall events were reported that exceeded 80mm. These contrast with more recent records, from 1967 and 2008, which list six recorded rainfall events that were greater than 80 mm (refer to Table 5.3).

The findings also indicate a seasonal shift of heavier rainfall events to later months in the year. Three heavy rainfall events occurred in the month of August, between 1926 and1966, compared to four events in November between 1967 and 2008. This is evidenced by the occurrence of heavier rainfall events in August of the earlier rainfall record. However, the more recent record of 1967 to 2008 shows that the heavy rainfall events have shifted to November, with four rainfall events exceeding 80mm.

Kundzewics (2004:4) indicates that, "tests fail to detect a weak trend or a change, which has not lasted long; but this cannot be interpreted as a demonstration of the absence of change". Subsequently, although the time period assessed in this case study was not particularly long, these findings are consistent with the projected rainfall trends associated with climate change, as forecasted by Midgley at al. (2005), and more recently by Midgley *et al.* (2010), and Nel *et al.* (2011).

These results may indicate the beginning of a preordained change. As climate change grows, the changes in the hydrological processes may become stronger and last longer; thus the change detection would be thereby confirmed (Kundzewics, 2004).

Unfortunately however, these findings present a weakness of the AMS, which is reflected upon by Katz (2010). Although the AMS manages to tabulate changes in patterns, it fails to determine the severity of the changes in extreme rainfalls, and climate variability, owing to the fact that the method only uses the highest figure for each year in the series. This is due to the approach operating under the assumption of stationarity. This means that researcher assumes that there will not be any systematical changes in climate during the period covered by the data (Katz, 2010).

The accommodation of additional figures from each year would provide a more definitive perspective on the increasing number of intense rainfalls in each of the more recent years. Subsequently, this would indicate the severity of change.

The current climate change projections also anticipate longer drier periods, and shorter more intense bursts of rainfall for the Western Cape. Similarly, the findings illustrated in Figure 5.3 suggest a declining frequency of annual rainy days over the period studied. This is indicated by an average of 32 rainy days per year between 1926 and 1935, compared with the 24 annual rainy days from 1999 to 2008. Significantly, 2008 recorded the least number of rainy days (9) for the 60-year study period, but with rainfall intensities of 14.3mm on average for that year. The figure was the fourth largest in the study period.

These extensive dry periods are important for developing ideal conditions for flash flooding, as during such periods the vegetation is provided with minimal water for growth, and the ground is thus baked and hardened for long durations (Spencer & Stensrud, 1998; Merz & Bloschl, 2009). The combination of these conditions, together with a steep gradient, allowed water to travel more rapidly down the catchment (Foody *et al.*, 2004).

6.3 River-flow related findings

The researcher also examined the changes in the frequency and intensity of extreme river flow records – by applying the EDA, AMS and PDS approaches.

The PDS results in Table 5.4 show that the largest peaks have been recorded in more recent years, specifically on 2 August 2006 and 23 November 2007. In addition, Table 5.5 reveals that between 1982 and 1995, only two river flows were recorded above $25m^3/s$. These were 16 November 1989 and 24 September 1993. This contrasts with the records from 1996 to 2008, which recorded six events above $25m^3/s$: in 1996, 2003, 2006 and 2007.

Table 5.5 further reveals that in terms of seasonality, 66% of the large river flow records took place between August and February, while 50% of the floods recording the highest river flows occurred between October and November.

The seasonal trend of the high river flow events is very similar to the seasonality trend displayed by the more recent rainfall records. This is consistent with the findings of Alexander (1993) and Smith and Petley (2009), who all regard rainfall as the main contributor to flood damage.

The operation of the PDS also presents an important point, as it approaches from a perspective of non-stationarity. By incorporating more than one figure from each year, the approach accommodates the possibility of changes to the climate system, and basin characteristics (Katz, 2010). Specifically, no direct correlations were assessed between the land-cover change and the river flows (partially owing to the fact that river discharge levels could not be assessed for the same timeframe).

However, the rate of land-cover change may also have been influential (Pattison & Lane, 2011:77). The years of 2006 and 2007 both had two floods in the 10 largest river-recorded discharges (Table 5.5). These coincided with the recorded agricultural expansion occurring between 1985 and 2008 in the upper catchment. Apart from showing an increasing intensity in such large discharges, the PDS indicates a growing severity of extreme hydrological activity.

6.4 Land-cover change findings and implications on floods

The study has sought to determine the extent to which land-cover characteristics associated with flooding in the catchment had changed over the period of 69 years. In the initial assessment, the researcher noted that the lower part of the catchment had a very high density of farms. These lie around the confluence, where the Groot Doornrivier meets the Olifants River. This is significant because, as reported of farmers on the Yangtze and Indus floodplains, the local farmers in the Kandelaars catchment are willing to incur the risk posed by flooding, through maximising the farming returns on more fertile floodplains further downstream (Alexander, 1993; Smith & Petley, 2009).

Further examination of the aerial photographs and satellite images over time, revealed land-cover change to be a significant feature in the Kandelaars catchment area. These show the changes can largely be attributed to agricultural expansion, primarily in the upper part of the catchment, which is closely interlinked with the settlement. Where settlement was detected, in the form of buildings and infrastructure, agricultural development subsequently followed.

The construction of this infrastructure has been enabled through urbanization, which Lambin *et al.* (2001) describe as the creating of urban-rural linkages in the form of transport networks (Meyer & Turner II, 1992). Farmers' accessibility to marginal lands, which in this case comprise the upper catchment, allowed for agricultural activity adjacent to their properties. Initially, agricultural activity was primarily concentrated in the lower catchment area; and it gradually extended further up the catchment.

The placement of the ostrich farms (Figure 5.9) is consistent with the contention of Pattison and Lane (2011:79) that pastoral fields, which are often viewed as the 'less favoured areas', are frequently located in the upper catchment area. Additionally, to support the growing agricultural activity, bodies of water were also constructed.

Unfortunately, the expansion of the linkages also develops an opportunity to continue the processes of land degradation, through movement from one location to the next, particularly where improper agricultural practices are prominent (Lambin *et al.*, 2001). In Oudtshoorn, over the decades, farmers have intensified and extensified their levels of ostrich, sheep and goat farming (Lambin *et al.*, 2001; Herling *et al.*, 2008; O'Farrel, 2010).

This has created more pressure on the land, resulting in further environmental degradation spread across the catchment area (Herling *et al.*, 2008).

Table 5.6 further indicates that the agricultural development has been responsible for most of the 10% reduction in natural shrubland in the catchment area. Agriculturally induced land-cover change has, in other studies, been shown to increase the intensity of runoff – and in some instances, also flooding (Yin & LI, 2001; Wang, 2004; Chang *et al.*, 2009; Pattison & Lane, 2011).

In this case study, such a modest change in the quantity of natural vegetation cover may not appear to increase runoff linked to flood damage. However, the location of extensive agricultural activities in the upper catchment area, alongside and between watercourses and below the confluence of the Groot Doornrivier and Kandelaars River, may have contributed to increased flood occurrence.

For instance, Pattison and Lane (2011) note that land use changes are localized in nature; and thus, the implications of these changes are seen to be more prominent for small catchments. Land management on the hill slopes adjacent to the river network could ease the transfer of water, which is documented to have greater implications in small basins (Pattison & Lane, 2011).

In Chapter Two, Cupido (2005), Herling *et al.* (2008) and Coetzee (n.d.), note that ostrich farming is environmentally damaging and may compact surfaces, thereby exacerbating runoff. The quantity of land degradation varies from one farm to the next; however, as noted from the field visit, in some instances ostrich rearing is clearly responsible for significant vegetation removal (Figure 5.11). This is in addition to the degradation caused by the ungulatory livestock, which are documented to degrade land (Pattison & Lane, 2011).

Despite the spatial distribution of ostrich farms across the catchment, the exact extent of degradation on all the ostrich farms could not be accurately assessed, due to the limitations of the tools selected for the study. Ground-truthing of selected visited farms indicated unevenness in the management of the birds and their density. As displayed in Figure 5.10, some farms are environmentally friendly. However, studies by Coetzee (n.d.), The Water Wheel (2010), and the South African Ostrich Business Chamber Biodiversity Unit (2009), all indicate that the ostrich farms in Oudtshoorn generally record flock numbers that are well beyond the recommended carrying capacity of the land.

Over-development, of this sort, which has been practised for over 40 years (Pattison & Lane, 2011), reportedly increases the risk of land degradation associated with greater overland flow (Chantalakhana, 1990; Semwal *et al.*, 2004; South African Ostrich Business Chamber Biodiversity Unit, 2009).

In similar circumstances, it has also been documented to coincide with a rise in flood risk (Pattison & Lane, 2011).

6.5 Recommendations for future research

6.5.1 Overview

This case study and its findings have determined that "the main problem with correlating changes in flooding magnitudes and frequency with a specific land-management change is that it is rare for all other possible factors that might influence flood generation to be constant during the period of correlation" (Pattison & Lane, 2011:77). Clearly, additional research is required to improve the understanding of important flood risk drivers in arid environments.

A number of other factors should, perhaps be taken into consideration for a more in-depth study. For instance, potential areas of future study include investigating speed of onset for flash floods, as well as the role that the seasonality of agricultural activities plays in river flows. Another issue includes examining the relationship between ostrich farming, land degradation and surface runoff (Pattison & Lane, 2011).

This study's geospatial results were also constrained by the limited sensitivity of the ground-cover analyses, combined with brief fieldwork. However, these shortcomings could be addressed by applying a programme, such as ERDAS (Bai & Dent, 2006; Reis, 2008). This is a useful programme for detecting different vegetation types, particularly through the analysis of specific spectral bands of the ground features.

6.5.2 Investigating the speed of onset for flash floods

As catchment characteristics evolve, hydrological modelling could be useful for determining the sharpness of peaks in the flood hydrographs of specific floods. Fluctuating gradients of the rising and falling limbs of the graphs, and changes in lag time between peak rainfall and peak discharge, indicate the extent to which land-cover change is affecting runoff (Bhunya *et al.*, 2011). For example, the Synthetic Unit Hydrograph and SCS methods would be particularly useful, as they take basin characteristics into account, such as veld type, and rainfall-runoff data.

6.5.3 Investigating the seasonality of agricultural activities related to river flow

The seasonality of the agricultural activities is also useful to study. This is influential on river flow, as the stage and type of the farming inevitably affect the precipitation captured, as well as the quantity of subsequent overland flow. For instance, fieldwork may be carried out to determine the specific type of arable or pastoral farming carried out around the catchment, over the course of the year.

This information can be corroborated with the rainfall data to determine the periods of the year when higher runoff levels may be anticipated (Pattison & Lane, 2011). Furthermore, this would indicate the types of agriculture which are less effective in retarding runoff.

6.5.4 Investigating the implications of ostrich densities, land degradation and river flow

In addition to fieldwork to make the analysis more robust, ERDAS can be used to study changing flood-risk profiles that are associated with ostrich-induced land-cover change. For instance, the number of ostriches on each of the identified farms in the study area could be established through interviews with farm owners and managers. Then, using GIS, this would allow for the illustration of bird concentrations and their distributions. These findings could then be related to the degree of ground degradation determined using ERDAS.

While this approach would require substantial ground-truthing (Her & Heatwole; 2007), it would generate useful information on the runoff associated with ostrich-induced land-cover change (Pattison & Lane, 2011).

6.6 Conclusion

This exploratory study into the changing pattern of flash flooding in the Kandelaars catchment has aimed to examine the respective contributions of rainfall and land-cover change to flood occurrence over the past 69 years.

The study has specifically sought to characterize the rainfall patterns from 1926 to 2008, in order to determine any changes in the frequency and magnitude of severe rainfall events. This has entailed the calculation of the return periods and the determination of the intervals between rainfall events – in order to identify the more extreme events. The study results indicate that there has been a reduction in both rainy days and the number of rainfall events within the Kandelaars catchment; although the total annual rainfall has remained constant at around 250mm per annum.

This has clear implications for river discharge. However, the results also indicate an increasing intensity of rainfall events when these do occur, along with a seasonal shift in rainfall to the later months of the year. These results are consistent with the observations of Midgley *et al.* (2010) and Midgley *et al.* (2005).

The study has also aimed to identify any changes in riverine river flow – in order to determine the changes in the frequency and magnitude of flood events. This was also done by calculating the recurring flood events, and then focusing on extreme river-flow events. The results showed close association between the intensity of the rainfall episodes and the river-flow records. For instance, as the intensity of rainfall records increased, the level of river-flow discharges also increased.

The discharge levels also followed a similar change in seasonal shift – to the latter parts of the year.

Lastly, the research has sought to determine and assess land use and land-cover changes that could influence flooding within the catchment area. The land-cover assessment involved the use of GIS in the form of ArcGIS 9.2, to analyse aerial photographs and satellite images, covering a time span of 69 years. Field visits were also carried out, to record the extent of degradation, as this varied across the catchment area.

Through the land-cover assessment, it was possible to understand and determine the different land-cover types that have changed, the extent to which these have changed, and the location within the catchment area where such changes took place (Bai & Dent, 2006; Reis, 2008). The results indicated that agricultural expansion has occurred at the expense of natural vegetation. This was largely the case in the upper catchment area, where the rainfall is the highest (average of 760mm per year compared to 250mm in the lower catchment), and adjacent to the tributaries that feed into the Groot Doornrivier.

These results show an increasing intensity of rainfall events, accompanied by prolonged dry spells in an area dependent on agriculture. Consequently, they highlight the challenges facing farmers in the Oudtshoorn Local Municipality. The agricultural expansion, together with continuous vegetation removal, increase the area's susceptibility to flooding, by enhancing the likelihood of overland flow (Cupido, 2005).

Erasmus *et al.* (2000), Midgley *et al.* (2010) and Nel *et al.* (2011) all state that the Western Cape is likely to be warmer and drier, indicating that bare surfaces are likely to be hardened more than they already are, in the current arid conditions. In addition to this, the forecasted increases in river flow owing to changes in CO_2 levels make the land even more prone to overland flow (Midgley, 2010).

Both of these factors could contribute considerably to flooding during extreme rainfalls.

The findings also underline the value of catchment-specific studies in areas exposed to weather extremes, especially those already sustaining heavy losses from floods (Foody *et al.*, 2004) and droughts, and in the case study area, the additional factor of avian influenza.

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Appendices

Appendix 1

Shows the commonly used plotting positions for frequency analysis. Source: SANRAL (2007)

Type	Plotting Position	Distribution
Wiebull (1939)	a = 1 & b = 0	Normal, Pearson 3
Blom (1958)	a = 0.25 & b = 0.375	Normal
Gringorten (1963)	a = 0.12 & b = 0.44	Exponential, EVI, GEV
Cunnane (1978) average of above two	a = 0.2 & b – 0.4	General purpose
Beard (1962)	a = 0.4 & b = 0.3	Pearson 3
Greenwood (1979)	a = 0 & b = 0.35	Wakeby, GEV

Appendix 2

Quality codes for river flow data. Source: Department of Water Affairs (2011)

1	Good continuous data
2	Good edited data
3	Preserved historical data
4	Q … Unaudited
5	Height derived from flow
7	Q … Good edited unaudited
26	$ … Gauge Plate Readings
27	& … Good Monthly Reading
50	S … Gap filled data
60	A … Above rating
65	E … Estimate
66	* … Program estimate
91	> … Greater than
92	< … Less than
150	^ … Rating Table Extrapolated - flows estimated
151	M … Missing data
152	~~ … Negative
160	N … No info for stage/disch determination
161	T … Rating Table Not Available
162	R … Rating Table Unreliable
163	G … Gate(s) - no spilling discharge
170	M … Missing data
171	M … Missing data
172	M … Missing data
173	? … Unreliable data
255	M … Missing data

Appendix 3

Heavy rainfall AMS return periods: Groot Doornrivier station 1926 to 1966

Gringorten (1963): 1926 to 1966				
Rank	Year	Rainfall (mm)	Annual Probability (1/y)	Return Periods (y)
1	01/01/1932	151.9	0.01	68.67
[redacted]				
3	12/01/1951	77.5	0.06	15.85
4	16/09/1947	74.4	0.09	11.44
5	06/04/1940	71.1	0.11	8.96
6	20/08/1962	62.0	0.14	7.36
7	29/08/1933	57.7	0.16	6.24
8	20/10/1953	57.0	0.18	5.42
9	23/05/1945	54.9	0.21	4.79
10	11/11/1950	54.4	0.23	4.29
11	15/05/1935	52.1	0.26	3.89
12	23/10/1926	50.8	0.28	3.55
13	29/03/1963	50.0	0.31	3.27
14	26/08/1927	44.5	0.33	3.03
15	16/09/1964	44.0	0.35	2.82
16	21/02/1955	42.0	0.38	2.64
17	13/07/1959	42.0	0.40	2.48
18	17/12/1937	41.1	0.43	2.34
19	29/01/1948	38.1	0.45	2.22
20	24/03/1956	37.5	0.48	2.10
21	28/05/1944	36.6	0.50	2.00
22	15/11/1938	35.6	0.52	1.91
23	22/08/1952	33.5	0.55	1.82
24	11/05/1949	33.0	0.57	1.75
25	14/12/1943	29.0	0.60	1.67
26	23/03/1965	28.5	0.62	1.61
27	07/01/1941	28.2	0.65	1.55
28	12/11/1934	27.9	0.67	1.49
29	12/03/1961	27.5	0.69	1.44
30	04/05/1958	25.0	0.72	1.39
31	27/03/1936	24.9	0.74	1.35
32	12/09/1957	24.5	0.77	1.30
33	15/05/1939	23.1	0.79	1.26
34	09/07/1929	21.1	0.82	1.23
35	27/03/1928	20.3	0.84	1.19
36	12/08/1930	18.5	0.86	1.16
37	14/10/1946	18.3	0.89	1.13
38	13/11/1960	17.0	0.91	1.10
39	06/03/1942	16.8	0.94	1.07
40	08/04/1931	13.2	0.96	1.04
41	14/09/1966	7.5	0.99	1.01

Appendix 4

Heavy rainfall AMS return periods: Groot Doornrivier station 1967 to 2008 (SANRAL, 2007)

Gringorten (1963): 1967 to 2008				
Rank	Year	Rainfall (mm)	Annual Probability (1/y)	Return Periods (y)
1	20/11/1996	118.0	0.01	68.67
2	02/08/2006	100.0	0.04	25.75
3	22/11/2007	88.0	0.06	15.85
4	06/11/2000	85.0	0.09	11.44
5	06/03/1994	84.4	0.11	8.96
[redacted]				
8	08/05/1977	66.5	0.18	5.42
9	22/08/1974	55.0	0.21	4.79
10	28/11/1995	50.5	0.23	4.29
11	23/03/2003	50.0	0.26	3.89
12	08/06/1975	49.5	0.28	3.55
13	22/07/1992	46.0	0.31	3.27
14	25/08/1970	45.5	0.33	3.03
15	27/04/1967	45.0	0.35	2.82
16	07/10/2008	42.0	0.38	2.64
17	19/12/1985	40.5	0.40	2.48
18	01/06/1968	40.0	0.43	2.34
19	28/10/1991	39.5	0.45	2.22
20	22/09/1983	39.0	0.48	2.10
21	04/04/1997	38.5	0.50	2.00
22	22/09/1987	37.5	0.52	1.91
23	05/02/1972	35.5	0.55	1.82
24	13/03/1989	33.5	0.57	1.75
25	15/06/1969	31.0	0.60	1.67
26	17/11/2001	31.0	0.62	1.61
27	28/04/1982	30.5	0.65	1.55
28	08/09/2002	30.5	0.67	1.49
29	01/11/1978	28.5	0.69	1.44
30	13/11/2005	28.5	0.72	1.39
31	05/03/1990	27.5	0.74	1.35
32	05/11/1976	27.0	0.77	1.30
33	20/07/1984	26.7	0.79	1.26
34	01/04/1971	26.5	0.82	1.23
35	21/04/1998	26.5	0.84	1.19
36	19/08/2004	25.0	0.86	1.16
37	24/05/1979	24.0	0.89	1.13
38	01/12/1980	23.5	0.91	1.10
39	24/10/1973	21.5	0.94	1.07
40	19/12/1988	21.0	0.96	1.04
41	04/08/1986	20.0	0.99	1.01

Appendix 5

Large discharge AMS return periods: Paardendrift station using: 1982-2008 (SANRAL, 2007)

Gringorten (1963): 1982 to 2008				
Rank	Date	River flow	Annual Probability (1/y)	Return Periods (y)
1	02/08/2006	51.51	0.02	45.33
2	23/11/2007	51.50	0.06	17.00
3	24/09/1993	49.09	0.10	10.46
4	22/11/1996	39.72	0.13	7.56
5	25/03/2003	35.33	0.17	5.91
6	16/11/1989	34.03	0.21	4.86
7	16/10/1992	23.47	0.24	4.12
8	27/07/1983	20.29	0.28	3.58
9	13/11/2000	16.90	0.32	3.16
10	07/03/1994	14.91	0.35	2.83
11	02/07/1982	12.61	0.39	2.57
12	30/11/1995	11.50	0.43	2.34
13	11/09/2002	10.94	0.46	2.16
14	21/12/1985	7.18	0.50	2.00
15	04/01/1986	7.14	0.54	1.86
16	28/05/1997	5.87	0.57	1.74
17	14/11/2008	4.26	0.61	1.64
18	13/04/2005	3.90	0.65	1.55
19	08/10/2004	3.56	0.68	1.46
20	19/12/1988	3.09	0.72	1.39
21	01/01/2001	2.82	0.76	1.32
22	22/07/1984	2.31	0.79	1.26
23	23/09/1987	2.06	0.83	1.20
24	01/11/1991	1.12	0.87	1.15
25	01/07/1990	0.91	0.90	1.11
26	26/08/1998	0.31	0.94	1.06
27	09/12/1999	0.16	0.98	1.02

Appendix 6

Visible land degradation caused by sheep and goats

Source: Field visit to Oudtshoorn, March 2012.